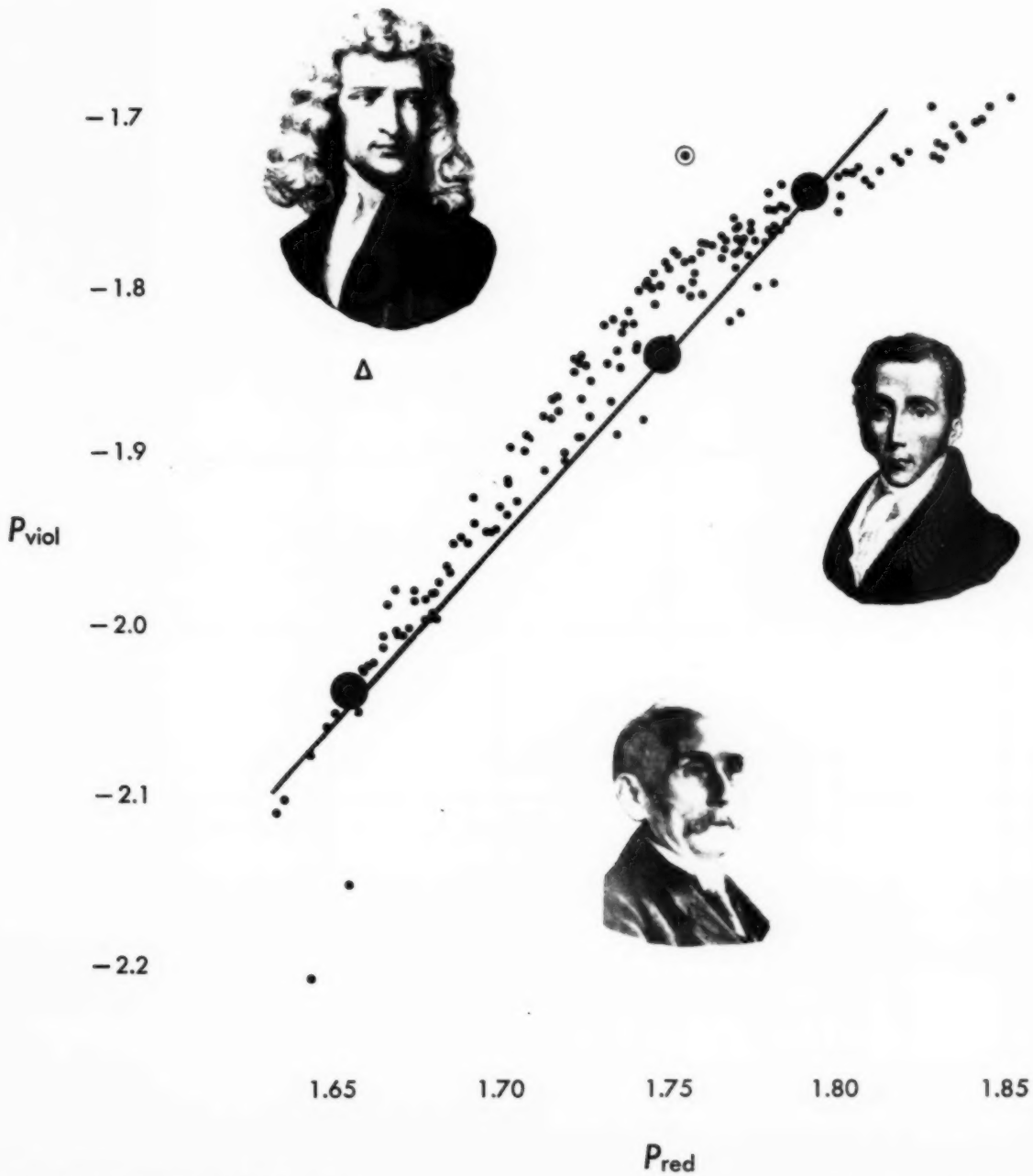
Applied Optics

June
1963



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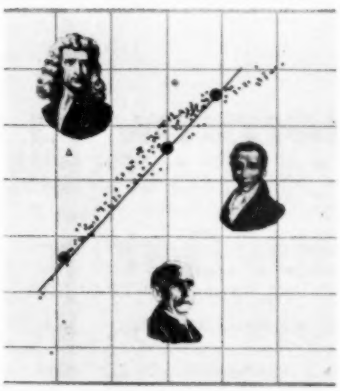
VOLUME 2
NUMBER 6
JUNE
1963

A monthly publication of the Optical Society of America

John N. Howard, Editor

Patricia R. Wakeling, Managing Editor

COVER: Upper left—Sir Isaac Newton (1642–1727), who discovered and explained the dispersion of optical glass, and, on the basis of inadequate experiments, concluded that the optical dispersion of all transparent substances is the same and therefore that achromatism is impossible. Upper right—Joseph von Fraunhofer (1787–1826), who recognized the nature of the absorption lines in the solar spectrum and used them as landmarks for optical dispersion, thus facilitating the design of achromatic lenses, in which rays of two colors coincide. Lower right—Otto Schott (1851–1935), who successfully introduced rare earths into optical glasses so that apochromatic lenses could be constructed, in which the rays for three colors coincide. The curve running diagonally through the middle is a plot of partial dispersion in the violet end of the visible spectrum against the partial dispersion in the red end. In the article on page 553, Max Herzberger shows that three glasses represented by points lying on a straight line, such as the three enlarged points, can be used for a superachromat, in which four rays coincide, and hence the rays over practically the entire spectrum, coincide. The open circle represents fluorite and the triangle, methyl methacrylate.



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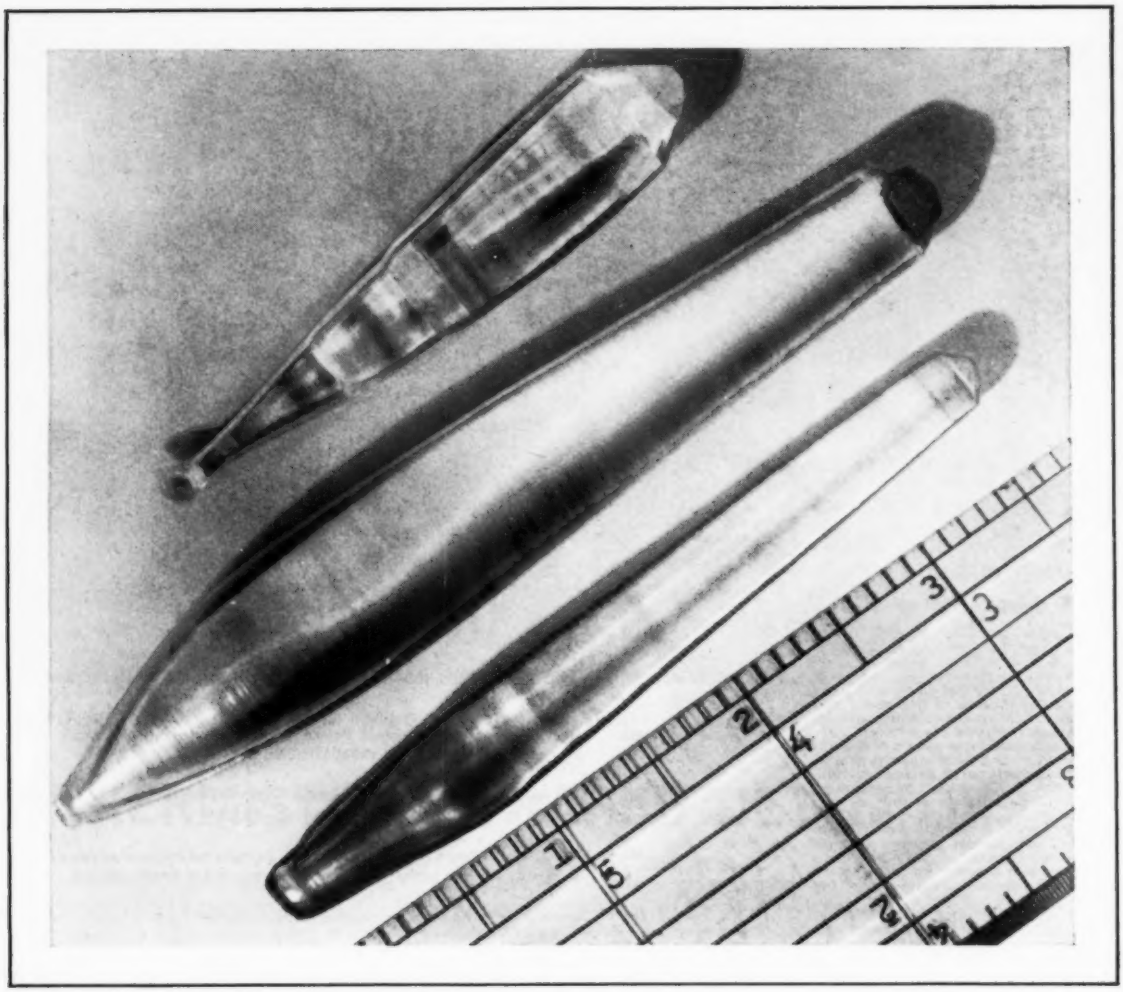

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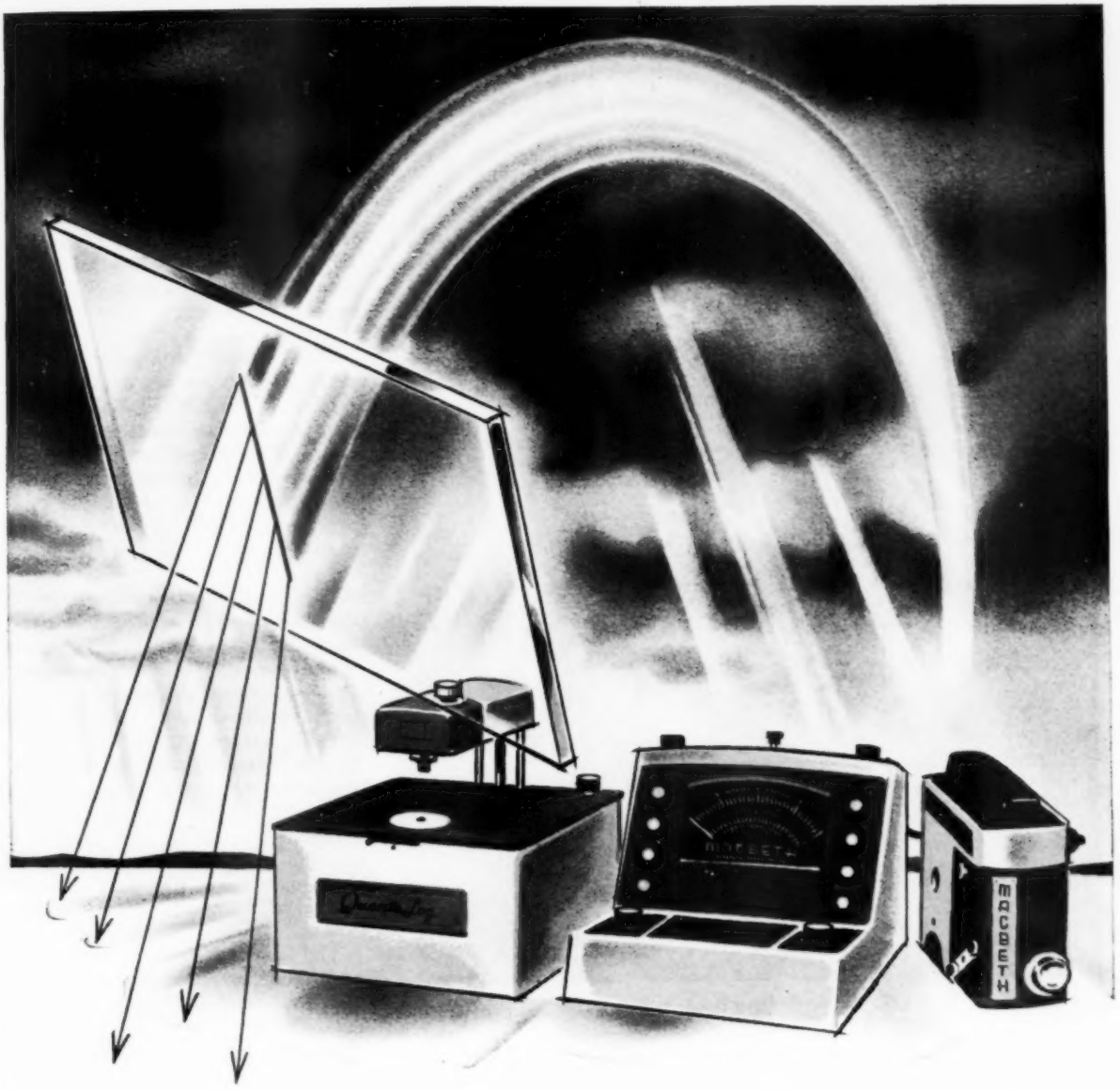

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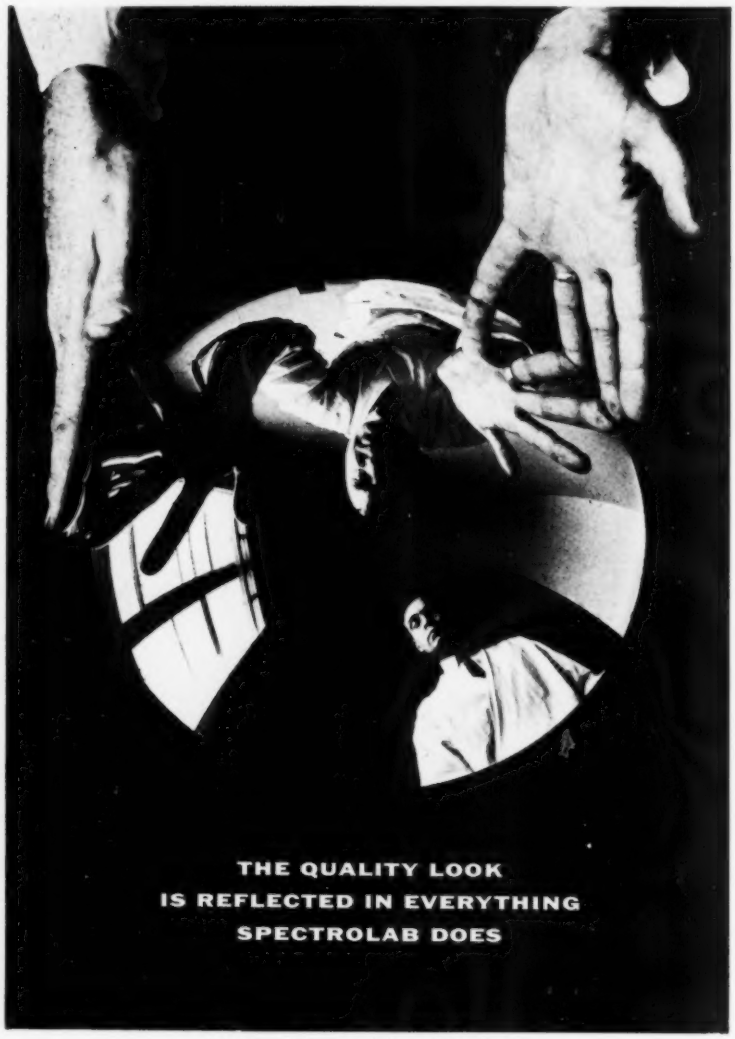

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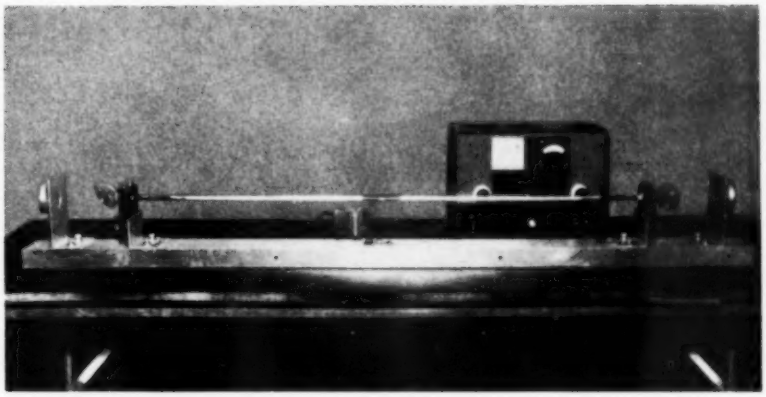

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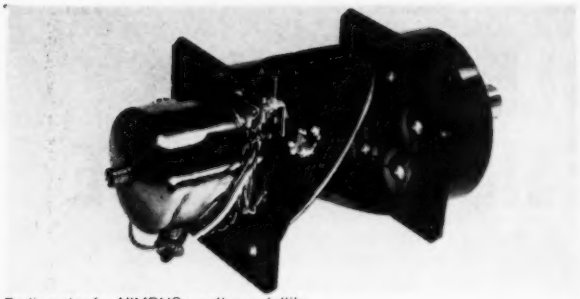

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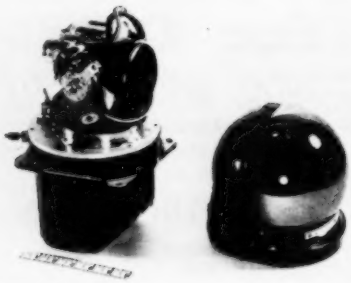

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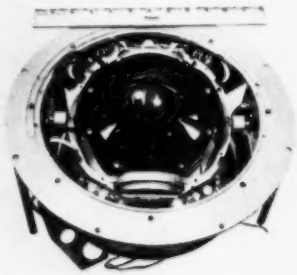

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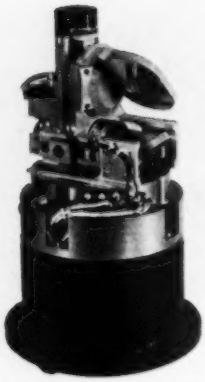

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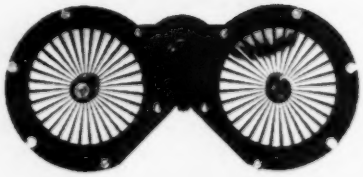

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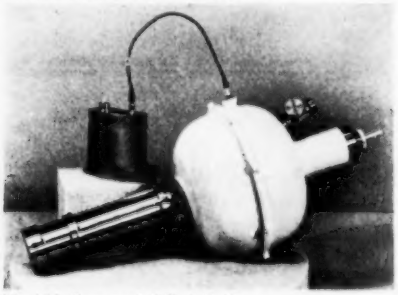

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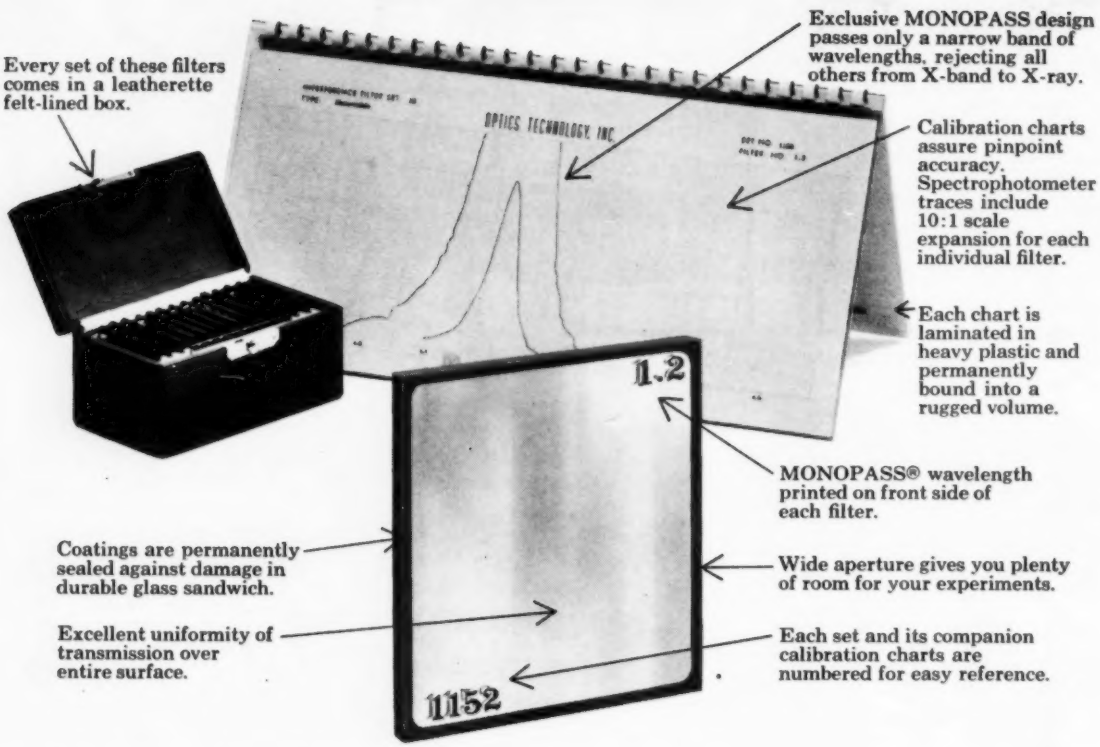
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The Design of Superachromatic Lenses

Max Herzberger and Nancy R. McClure

The history of achromatic lenses is briefly reviewed. The latest development is the superachromat, which is corrected for four colors. Since the dispersion of glass can be represented by an equation containing four constants, the superachromat is practically corrected for all colors. The application of the superachromatic principle to thick lenses is described and it is shown that a compound lens can be made superachromatic by making each of its separate components superachromatic.

A year or two ago, the senior author discovered a simple relation that leads to an improvement in the color correction of optical systems, and it is the purpose of this paper to describe how it can be applied in practice. The significance of this discovery will be made clearer by a brief review of the history of achromatism, which is fascinating in itself.

I. History

We start with Sir Isaac Newton's famous paper[1] on the dispersion of light. Would that authors today were allowed to write scientific papers in the same charming style! It starts:

> In the year 1666 . . . I procured me a Triangular glass-Prisme, to try therewith the celebrated *Phænomena* of *Colours*, And in order thereto having darkened my chamber, and made a small hole in my window-shuts, to let in a convenient quantity of the Suns light, I placed my Prisme at his entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby; . . . .

In this beautiful paper, Newton shows that light of different colors (wavelengths) travels with different speeds through glass and is therefore refracted differently. This explains why, in general, for different wavelengths, the image of an object formed by an optical system is focused at different distances from the lens and with different magnifications. These defects of imagery are called *chromatic aberrations*. Even for small apertures and fields, there are two such aberrations, those of position and of magnification. (Of course, if the aperture and field are increased, all subsequent errors have chromatic components that must be corrected in an optical instrument when it is to be used for light of many wavelengths.)

Newton investigated the dispersion of water and found it to be equal to that of crown glass, which at that time was the glass most used in optical lenses. From that observation, he drew the incorrect conclusion that all materials have the same relative dispersion. It can be shown that, if this were true, the chromatic errors of a lens system could not be corrected, and this was the conclusion Newton reached.[2] He suggested, therefore, that lenses for telescopes be replaced by mirrors, and thus for a century all telescopes were designed as mirror systems. This conclusion of Newton's is the more strange since he was familiar with glass similar to flint glass, which has a decidedly different dispersion, and which was used to make crystal vases and other luxury articles.

During the years 1729–1733, Chester Moor Hall, an English gentleman, by profession a justice of the peace, worked on the problem of improving the telescope because he, like many educated men of the time, was interested in astronomy as a hobby. He discovered that he could correct chromatic aberration by combining lenses of crown and of flint glass, and he had opticians make for him several telescopes containing such combinations of glasses. They became known to John Dollond, an industrialist, who, with his son Peter, commercialized them[3] and obtained a patent on achromats in 1758.

Hall's discovery was followed by the development of lens systems in all fields of optics and by the study of glasses and their dispersive qualities. The greatest progress was due to Joseph Fraunhofer,[4] who, by discovering the dark lines in the solar spectrum and the

The authors are with the Eastman Kodak Company, Rochester, New York.

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Communication No. 2267 from the Kodak Research Laboratories.

correspondence of the D-line with the bright line which he found in the spectrum of all lamp flames, made it possible to measure refractive indices for monochromatic radiations more accurately than before.

Although optical systems could be corrected for two wavelengths, it seemed impossible to correct them for three or more wavelengths. For the second time there was set forth an empirical law which seemed to make the progress of color correction hard or even impossible. If the partial dispersion for one wavelength is plotted against the ν-value (see Section II for the definition of ν), the points for practically all glasses seem to lie on a straight line. If the points did indeed lie on a straight line, the chromatic aberration for any wavelength would be independent of the choice of glasses when the system was corrected for two wavelengths.

For a long time, glasses that showed a deviation from the straight line on this plot were sought. Fraunhofer and later the glass factory of Otto Schott, which Ernst Abbe had created about 1881 to produce glass for the Zeiss works and to study the effects of different chemicals on dispersion, found glasses that seemed to deviate from the straight line. The addition of phosphate appeared to be especially effective in producing such deviations, but lenses fabricated from these glasses did not show the expected improvement. This was because the apparent deviation from the straight line arose only from striae in the samples, making it impossible to measure their refractive indices accurately.

By that time, the microscope had become the most exacting instrument; investigating objects that are invisible to the naked eye required increasing magnification. Abbe found that, for a given aperture, there is a limit to the useful magnification based on the laws of diffraction. An increase in the aperture of these lenses thus proved to be of the highest importance. This circumstance, in turn, created the problem of improving chromatic correction, which became the bottleneck of optical design at this time.

About 1870, Abbe found that fluorite has a decidedly unusual dispersion of the particular type desired and he incorporated it into his new "semiapochromatic" and "apochromatic" lenses, which conquered the microscope market for the firm of Zeiss. For two decades he preserved the secret of the new material, calling it "glass X" on the calculation sheets.

But fluorite, despite its favorable dispersion relations, has some undesirable characteristics, one being that, owing to the scarcity of large pieces in nature, its use for optical systems of large diameter has been limited. Other disadvantages are that it is soft and that the rate of change of its index with temperature is high. We have overcome the first hurdle, thanks to the late D. C. Stockbarger of the Massachusetts Institute of Technology, but the others are still obstacles to its use in instruments other than microscopes.

Despite the early disappointments, it was eventually found that the addition of certain chemicals does indeed change the secondary spectrum of glasses. This led to the so-called "short flints," which nevertheless deviate less from the normal than does fluorite. By means of these glasses, the chromatic correction of camera and telescope lenses of great focal length has been improved. Although this effort hitherto has not been systematic, apochromatic systems (i.e., systems corrected for more than two wavelengths) have been designed.

In the 1930's, C. W. Frederick and G. W. Morey developed a group of high-index glasses which do not contain silicon. These "Eastman Kodak glasses," which now are licensed to other glassmakers under the designation "lanthanum glasses," combine a high index with low dispersion, thus allowing weaker curvatures to be used for positive elements. When used in negative elements, they also have beneficial effects on the secondary spectrum.

During World War II, the lack of perfect color correction was again found to be responsible for the last trace of incorrigible errors in lens systems, this time for photographic objectives. For this reason, A. Bouwers in Holland and J. G. Baker of Harvard resorted anew to the design of mirror instead of lens systems. In an ingenious way, mirror systems were combined with afocal lens systems (systems with little or no power), thus concentrating most of the power in the mirror systems. Since mirror systems do not have color aberrations but do have other aberrations, such as curvature of field, the afocal systems could be used to balance these remaining aberrations. Telescopes, microscopes, and photographic objectives of this type have been designed. As long as optical systems were judged with respect to their resolving power, these systems received more and more attention. However, the obstruction of the mirror, which blots out some of the light from the object, has an undesirable effect on the diffraction images.

The validity of the law that the secondary spectrum in optical systems cannot be improved has been questioned by the senior author for a long time. In the 1930's, measurements of refractive indices in the infrared and ultraviolet regions were published for many glasses by R. and H. Kingslake and by H. Braukhoff. The data thus obtained showed sizable deviations from the linear plot obtained in the visible spectrum.

About two years ago we asked ourselves, "What characteristic must be demanded of three glasses to give a system of three lenses corrected for four wavelengths?" The answer is astonishingly simple. If one plots the partial dispersions (when these are defined in a special manner to be specified later) for two wavelengths, e.g., in the infrared and the ultraviolet, against each other, any three glasses whose points lie on a straight line will

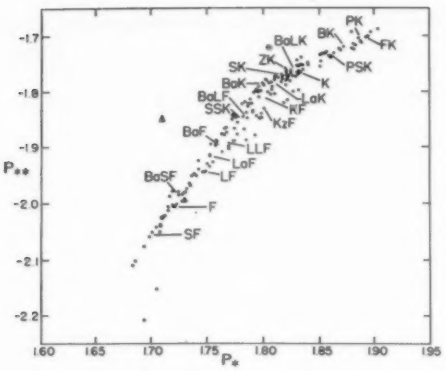

Fig. 1. Plot of $P_{**} = (n_F - n_{**})/(n_F - n_C)$ vs $P_* = (n_F - n_*)/(n_F - n_C)$ for selected glasses, largely from Schott catalog 350-E, and certain other materials (○—fluorite; △—methyl methacrylate). The types of glass are designated as in the Schott catalog. The materials used for a superachromat must lie on a straight line in this plot.

lead to a system corrected for four wavelengths. The plot shown in Fig. 1 demonstrates that, far from being a rarity, several hundred triads of glasses can be used to attain such correction.

In a previous paper,[5] the senior author showed that the dispersion curves of glasses are given by four constants, to an accuracy of about one unit in the fifth decimal place, throughout the whole spectrum from infrared to ultraviolet. If this law holds, the correction for four wavelengths should imply correction for the whole spectrum, and thus a new type of system was born which was called in this paper a "superchromat." In keeping with a recommendation of R. E. Stephens[6] of the Bureau of Standards, who has made a number of valuable contributions to achromacy and has tested the validity of our claims, we have decided to call such a system a *superachromat*.

But all these laws in their simple forms apply only to ideal lenses; that is, they are derived only for thin lenses in contact. In this paper, we shall discuss how superachromatic lenses with finite thicknesses and extended aperture and field can be designed.

II. Basic Formulas

For the sake of completeness, some of the arguments of the earlier paper[5] will be repeated in a slightly revised form. In that paper, it was shown that there exist four universal functions, $a_1(\lambda)$, $a_2(\lambda)$, $a_3(\lambda)$, and $a_4(\lambda)$, for all optical materials (which include glass, plastics, fluorite, and other homogeneous materials that are transparent in the visible region) such that the refractive index for any wavelength can be calculated if the indices are given for four.

The four wavelengths are chosen here as

$$\lambda_1 = \lambda_* = 1.014\ \mu,\ \lambda_2 = \lambda_C = 0.6563\ \mu,$$
$$\lambda_3 = \lambda_F = 0.4861\ \mu,\ \text{and}\ \lambda_4 = \lambda_{**} = 0.356\ \mu.$$

For almost all glasses, data corresponding to these wavelengths are given in the catalogs of the manufacturers. In Table I the values of a_1 to a_4 for selected wavelengths are reprinted from the earlier paper[5] for convenience. A choice of other wavelengths as standards would require only a linear transformation of these four universal functions.

We therefore have (abbreviating $n_\lambda - 1$ as μ_λ)

$$\mu_\lambda = a_1(\lambda)\mu_* + a_2(\lambda)\mu_C + a_3(\lambda)\mu_F + a_4(\lambda)\mu_{**}, \quad (1)$$

with

$$a_1 + a_2 + a_3 + a_4 = 1,$$

or the equivalent formula

$$\mu_F - \mu_\lambda = a_1(\mu_F - \mu_*) + a_2(\mu_F - \mu_C) + a_4(\mu_F - \mu_{**}). \quad (2)$$

We shall introduce the following definition, which deviates slightly from the customary definition of ν. We shall call

$$\nu_\lambda = \mu_F/(\mu_F - \mu_\lambda) \quad (3)$$

the *reciprocal dispersion* for the wavelength λ. Equation (2) then leads to

$$\frac{1}{\nu_\lambda} = a_1\frac{1}{\nu_*} + a_2\frac{1}{\nu_C} + a_4\frac{1}{\nu_{**}}. \quad (4)$$

Table I. Values of Universal Functions Appearing in Eq. (1) for Twelve Selected Wavelengths

$\lambda\ (\mu)$	Line	a_1	a_2	a_3	a_4
1.0140	*	+1.000000	0.000000	0.000000	0.000000
0.7682	A′	+0.192687	+1.051955	−0.276197	+0.031555
0.6563	C	0.000000	+1.000000	0.000000	0.000000
0.6438	C′	−0.012813	+0.966511	+0.051075	−0.004774
0.5893	D	−0.045919	+0.744598	+0.326272	−0.024952
0.5876	d	−0.046326	+0.735480	+0.336338	−0.025492
0.5461	e	−0.043764	+0.479049	+0.597795	−0.033080
0.4861	F	0.000000	0.000000	+1.000000	0.000000
0.4800	F′	+0.006659	−0.052699	+1.036699	+0.009340
0.4358	g	+0.057036	−0.394569	+1.193553	+0.143980
0.4047	h	+0.075791	−0.487634	+1.045064	+0.366779
0.3650	**	0.000000	0.000000	0.000000	+1.000000

The ratio

$$P_\lambda = \frac{\nu_C}{\nu_\lambda} = \frac{\mu_F - \mu_\lambda}{\mu_F - \mu_C} = \frac{n_F - n_\lambda}{n_F - n_C} \tag{5}$$

will be called the *partial dispersion* for the wavelength λ. Equation (4) can then be replaced by

$$P_\lambda = a_1 P_* + a_4 P_{**} + a_2. \tag{6}$$

The four data, μ_F, ν_C, P_*, and P_{**}, then describe a glass completely from the standpoint of our dispersion theory since they enable the refractive index to be computed for any intermediate wavelength. For instance, the definition of reciprocal dispersion and partial dispersion given by Eqs. (3) and (5) when combined give, for a desired wavelength λ,

$$\mu_\lambda = \mu_F - \mu_F(P_\lambda/\nu_C). \tag{7}$$

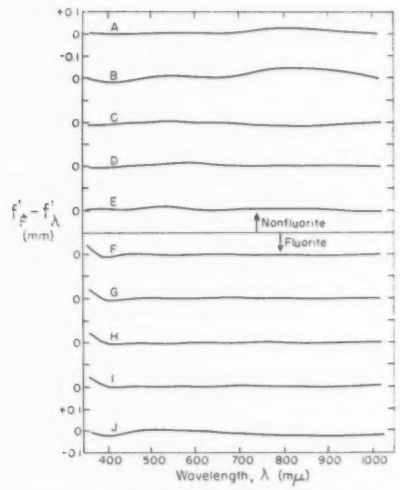

Fig. 2. Color curves of the ten thin-lens superachromatic triplets listed in Table II on the basis of a 100-mm focal length.

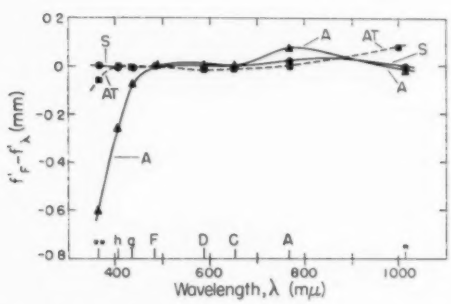

Fig. 3. Color curves of (A) typical apochromat, (S) superachromatic triplet A of Table II, and (AT) air-spaced fluorite triplet that approached superachromatic correction, all for f' = 100 mm.

After substituting Eq. (6) into this equation, we get

$$\mu_\lambda = \mu_F - \mu_F(a_1 P_* + a_4 P_{**} + a_2)/\nu_C. \text{ Q.E.D.} \tag{8}$$

The focal length of a single thin lens is given by

$$\phi = \mu(\rho' - \rho''), \tag{9}$$

where ρ' and ρ'' are the front and back curvatures of the lens and ϕ, the power of the lens, is the reciprocal of the focal length. The power of a system of thin lenses (with individual powers ϕ_i) in contact is

$$\Phi = \Sigma\phi_i \tag{10}$$

and from Eq. (1) we find

$$\Phi_F - \Phi_\lambda = a_1(\Phi_F - \Phi_*) + a_2(\Phi_F - \Phi_C) + a_4(\Phi_F - \Phi_{**}), \tag{11}$$

in which we can replace

$$\Phi_F - \Phi_\lambda = \Sigma(\phi_F/\nu_\lambda). \tag{12}$$

A superachromat must fulfill the following conditions:

$$\begin{aligned} \Phi_F - \Phi_C &= 0 = \Sigma\phi_F/\nu_C, \\ \Phi_F - \Phi_* &= 0 = \Sigma\phi_F/\nu_*, \\ \Phi_F - \Phi_{**} &= 0 = \Sigma\phi_F/\nu_{**}. \end{aligned} \tag{13}$$

We have the following equations for three elements:

$$\begin{aligned} &\phi_{F1}/\nu_{C1} + \phi_{F2}/\nu_{C2} + \phi_{F3}/\nu_{C3} = 0, \\ &\phi_{F1}/\nu_{*1} + \phi_{F2}/\nu_{*2} + \phi_{F3}/\nu_{*3} = 0, \\ &\phi_{F1}/\nu_{**1} + \phi_{F2}/\nu_{**2} + \phi_{F3}/\nu_{**3} = 0. \end{aligned} \tag{14}$$

The determinant of these equations,

$$\begin{vmatrix} 1/\nu_{C1} & 1/\nu_{C2} & 1/\nu_{C3} \\ 1/\nu_{*1} & 1/\nu_{*2} & 1/\nu_{*3} \\ 1/\nu_{**1} & 1/\nu_{**2} & 1/\nu_{**3} \end{vmatrix}, \tag{15}$$

must vanish. Multiplying the first column by ν_{C1}, the second by ν_{C2}, and the third by ν_{C3}, we obtain

$$\begin{vmatrix} 1 & 1 & 1 \\ P_{*1} & P_{*2} & P_{*3} \\ P_{**1} & P_{**2} & P_{**3} \end{vmatrix} = 0, \tag{16}$$

which means that, in the plot of P_{**} vs P_*, the points for the three glasses lie on a straight line.

The corresponding values of the powers are found in the following way:

Solving the first two equations of Eqs. (14) for ϕ_3, setting them equal to each other, and substituting $P_\lambda = \nu/\nu_\lambda$ gives

$$\phi_1/\nu_{C1}:\phi_2/\nu_{C2} = (P_{*2} - P_{*3}):(P_{*3} - P_{*1}). \tag{17}$$

Analogously, using the same two equations and solving for ϕ_1 gives

$$\phi_2/\nu_{C2}:\phi_3/\nu_{C3} = (P_{*3} - P_{*1}):(P_{*1} - P_{*2}). \tag{18}$$

From Eqs. (17) and (18) we obtain the following formulas for the powers of the individual elements of a superachromat:

$$\begin{aligned} \phi_1 &= k(P_{*2} - P_{*3})\nu_{C1}, \\ \phi_2 &= k(P_{*3} - P_{*1})\nu_{C2}, \\ \phi_3 &= k(P_{*1} - P_{*2})\nu_{C3}, \end{aligned} \tag{19}$$

Table II. Glass Constants of Ten Thin Superachromatic Triplets of Unit Power[a]

Comb.	Element	μ_F	ν_C	P_*	P_{**}	ϕ
			Without Fluorite			
A	1	0.52242	70.31	1.87887	−1.71332	+4.286179
	2	0.64576	44.57	1.80193	−1.86680	−4.484745
	3	0.73463	30.22	1.68367	−2.10366	+1.198566
B	1	0.49230	70.73	1.89655	−1.69397	+4.353835
	2	0.64576	44.57	1.80193	−1.86680	−5.466357
	3	0.66122	34.58	1.70659	−2.04132	+2.112522
C	1	0.52242	70.31	1.87887	−1.71332	+4.489267
	2	0.62319	44.61	1.78382	−1.88762	−6.413435
	3	0.67756	36.59	1.70788	−2.02484	+2.924168
D	1	0.52242	70.31	1.87887	−1.71332	+4.821587
	2	0.62319	44.61	1.78382	−1.88762	−7.028265
	3	0.64908	36.06	1.71056	−2.02167	+3.206678
E	1	0.52242	70.31	1.87887	−1.71332	+4.717009
	2	0.62319	44.61	1.78382	−1.88762	−6.871062
	3	0.63777	36.28	1.71047	−2.02218	+3.154053
			With Fluorite			
F	1	0.43705	95.84	1.80482	−1.72807	+2.015105
	2	0.89563	41.81	1.75117	−1.88562	−1.968550
	3	0.67756	36.59	1.70788	−2.02484	+0.953445
G	1	0.43705	95.84	1.80482	−1.72807	+2.097892
	2	0.89563	41.81	1.75117	−1.88562	−1.960115
	3	0.66817	34.50	1.70418	−2.03872	+0.862223
H	1	0.43705	95.84	1.80482	−1.72807	+2.064021
	2	0.89563	41.81	1.75117	−1.88562	−2.089979
	3	0.64908	36.06	1.71056	−2.02167	+1.025958
I	1	0.43705	95.84	1.80482	−1.72807	+2.050473
	2	0.89563	41.81	1.75117	−1.88562	−2.073647
	3	0.63777	36.28	1.71047	−2.02218	+1.023174
J	1	0.43705	95.84	1.80482	−1.72807	+2.380189
	2	0.57008	45.94	1.76210	−1.90887	−1.968007
	3	0.62914	32.65	1.70317	−2.15361	+0.587818

[a] Many other combinations are possible but these have especially low powers (shown in the last column) for their individual elements.

Table III. Glass Constants for Thin Color-Corrected Lenses of Unit Power, Powers of Individual Elements, and Sums of Absolute Values of These Powers[a]

Element	μ_F	ν_C	P_*	P_{**}	ϕ	$\sum\lvert\phi\rvert$
			Apochromats			
1	0.56982	51.66	1.77879	−1.84950	10.050584	
2	0.75603	46.52	1.77846	−1.88062	−9.050584	19.101168
1	0.53584	52.33	1.78711	−1.83203	8.635314	
2	0.75607	46.27	1.78825	−1.84700	−7.635314	16.270628
1	0.53239	55.34	1.80249	−1.81081	13.732010	
2	0.76351	51.31	1.80175	−1.81116	−12.732010	26.464020
1	0.53239	55.34	1.80249	−1.81081	5.138347	
2	0.64576	44.57	1.80193	−1.86680	−4.138347	9.276694
			Superachromats			
1	0.52242	70.31	1.87887	−1.71332	+4.286179	
2	0.64576	44.57	1.80193	−1.86680	−4.484745	
3	0.73463	30.22	1.68367	−2.10366	+1.198566	9.969490
1	0.49230	70.73	1.89655	−1.69397	+4.353835	
2	0.64576	44.57	1.80193	−1.86680	−5.466357	
3	0.66122	34.58	1.70659	−2.04132	+2.112522	11.932714
1	0.43705	95.84	1.80482	−1.72807	+2.015105	
2	0.89563	41.81	1.75117	−1.88562	−1.968550	
3	0.67756	36.59	1.70788	−2.02484	+0.953445	4.937100

[a] The requirement for apochromats is that $P_{1*} = P_{2*}$; for superachromats, that $P_{i**} = a + bP_{i*}$, where i represents each of the elements and a and b are constants for a given lens.

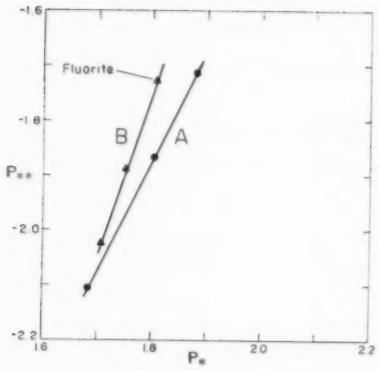

Fig. 4. Plot of P_{**} vs P_* for (A) an all-glass and (B) a fluorite superachromatic triplet.

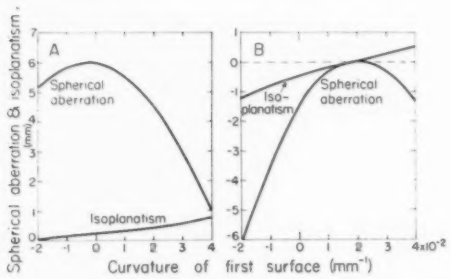

Fig. 5. Marginal spherical aberration and isoplanatism as a function of bending for triplets of 100-mm focal length made from the materials plotted in Fig. 4. The bending is indicated by the curvature of the first surface in reciprocal millimeters.

where k is a proportionality factor. If k is chosen as

$$k = 1/\Sigma(\phi_1 + \phi_2 + \phi_3),$$

the system will have unit focal length.

III. Calculation and Analysis of a Superachromatic Element

To make a superachromatic lens, Eq. (16) shows that we must choose three glasses lying on or near a straight line on a plot of P_{**} vs P_* (Fig. 1). Since the order of the three lenses does not matter, we can assume $P_{*1} > P_{*2} > P_{*3}$. Moreover, large differences in ν-value are needed to keep the powers low. To a first approximation,[7] P_λ is a linear function of ν, so we postulate that

$$P_{*1} - P_{*2} \geqq 0.07 \text{ and } P_{*2} - P_{*3} \geqq 0.07.$$

On the basis of these restrictions, the authors found approximately a thousand combinations of glasses that would give superachromats. No more than 200 of these contain fluorite, showing that fluorite is not an essential ingredient of a superachromat. Table II lists ten of these combinations, five containing only glass and five in which one element is made of fluorite. (The latter combinations will hereafter be called simply "fluorite lenses.")

The last column shows the thin-lens powers of each element for a system of unit focal length. The combinations of glasses are selected to give as low powers to the individual elements as possible.* The sum is especially small when fluorite is used because the difference in ν-value is great and the individual powers are therefore low.

The relations between focal length and wavelength for the ten combinations listed in Table II were calculated, and they are plotted in Fig. 2. These curves bear out the prediction that the correction for a thin-lens system is practically perfect. Although the all-glass combinations show a little aberration in the visible region, they remain well corrected into the ultraviolet; the fluorite combinations are almost perfect in the visible although they begin to show increasingly significant amounts of aberration below 400 mμ.

A comparison of the superachromatic type of correction with the apochromatic type is given in Fig. 3, where S is the curve of superachromatic combination A (Table II and Fig. 2) and curve A is a typical apochromatic curve. Not only does the latter curve depart slightly from the horizontal in the middle of the visible region but it also breaks rapidly at about 480 mμ, whereas the superachromatic curve remains horizontal beyond 400 mμ. Curve AT is for an apochromatic triplet containing fluorite, designed by H. O. Hoadley[8] and the senior author in 1943, which, although designed by the usual trial-and-error methods, approached superachromatic correction.

When thicknesses are introduced, the longitudinal and lateral aberrations of a cemented superachromat are not easily corrected at the same time for all colors. However, by slightly separating two of the components of the triplet, one more variable becomes available. (Such a triplet will be called "air-spaced" hereafter.) A large number of glass combinations were investigated but the results were so similar that it is sufficient to present them for only two typical combinations, of which one contains fluorite. The dispersion relations of these combinations are indicated in Fig. 4.

The first problem was to improve spherical aberration and isoplanatism (coma) by bending. An $f/10$ cemented triplet was investigated for both positive and negative powers, for real objects at infinity and at finite distances, and even for a virtual object. The results were equivalent in all cases. With a single superachromatic triplet not containing fluorite, one aberration or the other could be corrected, as shown by

* It may be of interest that the sum of the absolute powers of the individual elements in a superachromat is, in general, smaller than that of a comparable apochromatic doublet (corrected for three colors), as indicated in Table III.

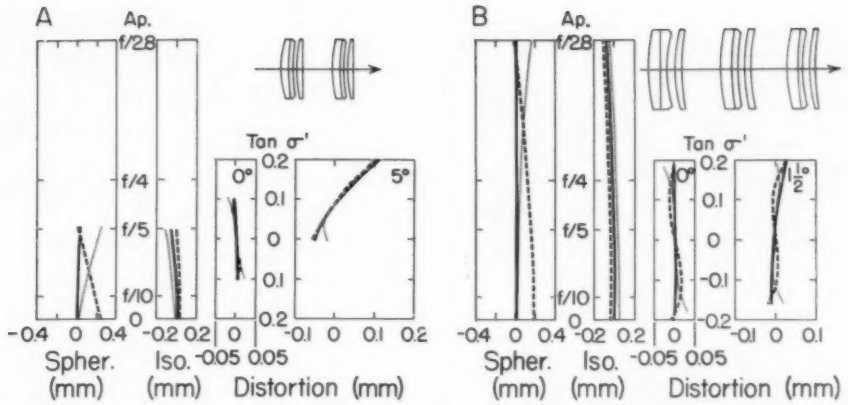

Fig. 6. Superachromatic combinations of (A) two and (B) three all-glass, air-spaced triplets of 100-mm focal length with their error curves. The first two curves for each lens represent, left to right, spherical aberration and isoplanatism (coma) as a function of aperture; the third and fourth represent, respectively, distortion on the axis and departure from the Gaussian image point as a function of slope angle σ' of emergent ray. Solid curves, F-line; broken curves, A′-line; dotted curves, h-line of spectrum. Combination B was designed for a comparatively small field. Distortion as defined here means the deviation of the intersection point of a ray with the image plane from the Gaussian image point. This is a generalization of the usual definition, which is restricted to principal rays.

graph A of Fig. 5; with a fluorite element, both aberrations could be corrected, as shown at B. This indicates that nearly all lens designs can be corrected superachromatically.

To increase the useful aperture, two or more superachromatic triplets must be combined. Two air-spaced triplets gave a good $f/5$ superachromat, shown with its error curves at A in Fig. 6. With a combination of three superachromats, as shown at B, it is possible to design a microscope objective in which both spherical aberration and isoplanatism are corrected for apertures even greater than $f/2.8$.

Figure 7 shows a sketch of a superachromatic Petzval-type lens with extremely fine correction for an aperture of $f/2.8$ over a field of 2° from the axis. The spot diagrams for three field positions on each of three image planes are shown in Fig. 8. To give an idea of the excellence of the corrections, the size of the Airy disk is indicated by the circle AD at the right.

It will be noticed that the superachromats described in this paper are either triplets without large air spaces or are spaced combinations of such triplets. To see whether single separated elements can be corrected as well as a superachromat for color, we studied a Cooke triplet. This lens consists of three widely spaced single elements, and as ordinarily designed, two colors can easily be made coincident by proper spacing, but then residual errors are left in the other colors. Three glasses lying on a straight line in the P_{**}–P_* diagram were selected, and attempts were made to design a superachromatic lens of this type, but we did not succeed in balancing the intermediate color errors. It appears, therefore, that, to take advantage of the superachromatic principle, each separated element or cemented combination that is not of low power must be individually superachromatic. Notwithstanding this inconvenience, we believe that the superachromatic principle should be extremely valuable when the total elimination of chromatism is of cardinal importance, and, although only lenses covering small fields have been discussed here, there is no basic reason to believe that superachromatic lenses covering large fields cannot be designed.

Fig. 7. Sketch of $f/2.8$ superachromatic Petzval-type lens in which two components are cemented fluorite superachromatic triplets.

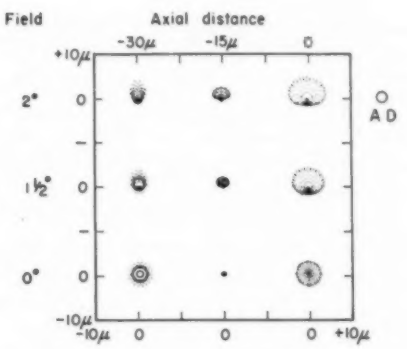

Fig. 8. Spot diagrams of $f/2.8$ Petzval-type lens sketched in Fig. 7 for each of three field angles and each of three axial positions measured from the Gaussian focus. The size of the first dark ring in the Airy pattern is indicated by the circle AD.

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Meetings Calendar

June

—	APS, summer mtg., Buffalo, N.Y. *K. K. Darrow, 538 W. 120 St., New York 27, N.Y.*
4–7	German Soc. for Applied Optics, Ann. Mtg., Braunschweig *H. Volkmann, Deutsche Gesells. für Angewante Optik Schriftfuhrer, Zeppelinstr. 23, 792 Heidenheim, Germany*
4–8	Soc. of Phys. Chem., ann. mtg., Paris *G. Emschwiller, Soc. de Chimie Physique, 10, rue Vauquelin, Paris 5, France*
6–8	Chem. Inst. of Canada, 46th Natl. Conf., Toronto, Ont. *CIC, 48 Rideau St., Ottawa 2, Ont., Canada*
6–9	Canadian Assoc. of Physicists, Laval U., Quebec City *L. Katz, U. of Saskatchewan, Saskatoon, Canada*
7–13	European Ophthalmological Soc. 2nd Cong., Vienna *J. François, 15, pl. de Smet de Naeyer, Ghent, Belgium*
10–14	Triple Commission on Spectroscopy, Columbus *H. H. Nielsen, Ohio State U., Columbus, Ohio*
10–14	Molecular Structure and Spectroscopy, 18th symp., Columbus *H. H. Nielsen, Ohio State U., 174 W. 18 Ave., Columbus 10, Ohio*
10–21	Industrial Use of the Polarizing Microscope, McCrone Res. Inst. *J. A. Reffner, McCrone Res. Inst., 451 E. 31 St., Chicago 16, Ill.*
13–Aug. 9	Geometric Optics Summer Course, Indiana U. *R. W. Everson, Div. of Optometry, Indiana U., Bloomington, Ind.*
17–21	Carbon Conf., U. of Pittsburgh *R. A. Friedel, U.S. Bureau of Mines, 4800 Forbes Ave., Pittsburgh 13, Pa.*
17–24	CIE, Hofburg Palace, Vienna, Austria
17–28	AFOSR Summer Scientific Seminar on Topics in Optics, Cloudcroft, N.M. *AFOSR Seminar, P.O. Box 1053, Holloman AFB, N.M.*
18–26	Internatl. Comm. on Illumination, 15th Cong., Vienna, Austria
23–28	ASTM Ann. Mtg., Chalfonte-Haddon Hall, Atlantic City, N.J. *ASTM, 1916 Race St., Philadelphia 3, Pa.*
24–26	APS, Buffalo *K. K. Darrow, 538 W. 120 St., New York 27, N.Y.*
24–26	Internatl. Astrophysics Symp., Liège *M. Migeotte, Inst. d'Astrophysique, Cointe-Sclessin, Belgium*
24–27	Groupement pour l'Avancement des Methodes Spectrographiques, 25th Cong., Paris *GAMS, 1, rue Gaston Boissier, Paris 15, France*
24–28	Gordon Conf. on Magnetic Resonance, Tilton School, Tilton, N.H.
24–July 5	Thermal Design of Spacecraft Course, UCLA *Engr. Ext., Engr. Bldg. II, U. of Calif., Los Angeles 24, Calif.*
25–29	Oil and Colour Chemists' Assoc., biennial conf., Scarborough, England

July

1–5	IUPAC Internatl. Symp. on Macromolecular Chem., Paris *Symp. Sec., Lab. de Chimie Physique, 11, rue Pierre Curie, Paris 5, France*
1–5	Gordon Conf. on Chemistry and Physics of Space, Tilton School, Tilton, N.H.
1–14	Applications of Quantum Mechanical Methods to the Study of Molecular Properties, Menton *R. Daudel, Centre de Mechanique Ondulatoire Appliquee, 23, rue du Maroc, Paris 19, France*
2–5	Internatl. Symp. on Free Radicals, 6th, Cambridge *A. B. Collear, U. of Cambridge, Lensfield Rd., Cambridge, England*
5–9	IUPAC Conf., London *Sec., IUPAC Conf., 47 Belgrave Sq., London, SW1, England*
8–13	Ionization Phenomena in Gases, Orsay *P. Hubert, CENFAR, B. P. No. 6, Fontenay-aux-Roses, Seine, France*
8–19	Industrial Use of the Polarizing Microscope, McCrone Res. Inst. *J. A. Reffner, McCrone Res. Inst., 451 E. 31 St., Chicago 16, Ill.*
8–27	Summer Course in Modern Optics, Inst. of Optics, U. of Rochester *Inst. of Optics Summer Course, U. of Rochester, River Campus Station, Rochester 20, N. Y.*
10–17	IUPAC Congress, London *Sec., IUPAC Congress, 47 Belgrave Sq., London, SW1, England*
15–19	IUPAP, 2nd Internatl. Conf. of Nuclidic Massec, Vienna, Austria
15–26	Optical Physics and Its Applications Course, UCLA *Engr. Ext., Engr. Bldg., U. of Calif., Los Angeles 24, Calif.*
18–23	IUPAC Symp. on Thermodynamics and Thermochemistry, Lund *S. Sunner, Thermochem. Lab., Lund U., Lund, Sweden*
22–26	Physics of Electronic and Atomic Collisions, London *Conf. Sec., Physics Dept., University Col., Gower St., London, W.C. 1, England*
22–26	Symp. on Microscopy, Brighton, England *E. C. Bilby, McCrone Res. Inst., 451 E. 31 St., Chicago 16, Ill.*
22–27	European Molecular Spectroscopy Mtg., Budapest *A. Kovasz, Hungarian Academy of Sciences, Budapest, Hungary*
24–Aug. 9	The Microscope in Criminalistics, McCrone Res. Inst. *J. A. Reffner, McCrone Res. Inst., 451 E. 31 St., Chicago 16, Ill.*
30–Aug. 9	U. of Minn. Molecular Spec. Lab Summer Courses in IR Spectroscopy *Director, Center for Continuation Study, U. of Minn., Minneapolis 14, Minn.*

August

—	Fourth Australian Spectroscopy Conf., Australian Natl. U., Canberra, Australia
4–9	Internatl. Conf. and Exhibit on Aerospace Support, Wash., D.C. *Box 6635, Wash., D.C.*
5–16	Radiation Thermometry Course, UCLA *Engr. Ext., Engr. Bldg., U. of Calif., Los Angeles 24, Calif.*
12–16	Gordon Conf. on Instrumentation, Colby Jr. Col., New London, N.H.
12–16	Gordon Conf. on Chemistry and Physics of Solids, Kimball Union Acad., Meriden, N.H.
13–17	5th Ann. Gas Chromatography Session, Fisk U. *N. Fuson, Fisk Infrared Inst., Fisk U., Nashville 8, Tenn.*
13–23	14th Ann. Infrared Spectroscopy Inst., Fisk U. *N. Fuson, Fisk Infrared Inst., Fisk U., Nashville 8, Tenn.*
15–30	Internatl. Assoc. of Meteorology and Atmospheric Physics, Berkeley, Calif. *W. L. Godson, Meteorological Office, 315 Bloor St. W., Toronto 5, Ont., Canada*

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Infrared Transmission through the Atmosphere

A. E. S. Green and M. Griggs

An analytic expression for transmission in terms of optical path and pressure is combined with an analytical expression for equivalent atmospheric path length in terms of height and slant angle to yield a single expression for transmission in terms of height and slant angle. Separate equations are developed for carbon dioxide absorption, and for water vapor absorption. The latter may be used with almost any water vapor distribution in the atmosphere. A function due to Chapman is used instead of the usual secant factor for slant paths in order to extend the use of the equations to angles of incidence up to 90°. Wavelength dependent parameters are presented based upon Zachor's analytic fits to laboratory data.

I. Introduction

It would be of great value to have a simple model describing infrared transmission through the atmosphere along slant paths. In an effort to achieve mathematical accuracy, the methods to date have sacrificed simplicity, and have resulted in lengthy and complicated procedures. Such complications do not seem to be altogether warranted, as the deviations of the actual water vapor distribution from the model used probably introduce more error than would other approximations.

The object of this paper is to provide an approximate analytical approach which will take into account any simplified water vapor distribution. All previous results have been restricted to one or two distributions.

II. Previous Work

In 1955 Howard *et al.*[1] published near infrared absorption data obtained in the laboratory for different path lengths and different pressures. Empirical relations were fitted to these measurements, and have been used by later authors to compute the transmission through the atmosphere.

Carpenter *et al.*[2] gave a method whereby a path of variable pressure, temperature, and density of absorbing gases can be reduced to an equivalent path, at constant pressure and temperature, for direct substitution into the empirical equations of Howard *et al.* Results were obtained for the ARDC Model Atmosphere, but only for water vapor distributions with mixing ratio or relative humidity constant with height. These have a limited application to the real atmosphere.

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Thomson and Downing[3] used the band model of Elsasser[4] to calculate the transmission of CO_2 through the atmosphere. Choosing summer and winter model distributions of water vapor, they calculated the transmission through the atmosphere in the 2–5 μ region. To do so, they devised a procedure which permitted them to utilize Carpenter's results for constant mixing ratios. Their results were presented in graphical form for vertical transmission only, although they provided a graphical procedure for scaling the results to other angles.

Green, in an effort to apply the transmission calculations of Thomson and Downing proposed that their results be fitted by the analytical formula

$$T = \exp(-k \sec^{n}\theta e^{-y/h}),$$

a formula which may be inferred from elementary considerations assuming that there is only one absorbing species.

Green and Downing[5] fitted this formula to the results of Thomson and Downing not only for narrow spectral intervals but also for several rather broad intervals. The fits obtained were relatively good in certain instances although in several cases the deviations were fairly large. An effort was made to determine whether these discrepancies were a limitation of the formula or of the previously calculated transmission values.

At the same time a report by Zachor[6] gave an alternative method for determining the transmission based on the results of Howard *et al.* Zachor accepts the empirical formula fits to the Goody model for water vapor by Howard *et al.*, but in an intensive study of the carbon dioxide data, he obtains new empirical fits at various discrete wavelengths. To apply the results to practical problems, one must first calculate the equiva-

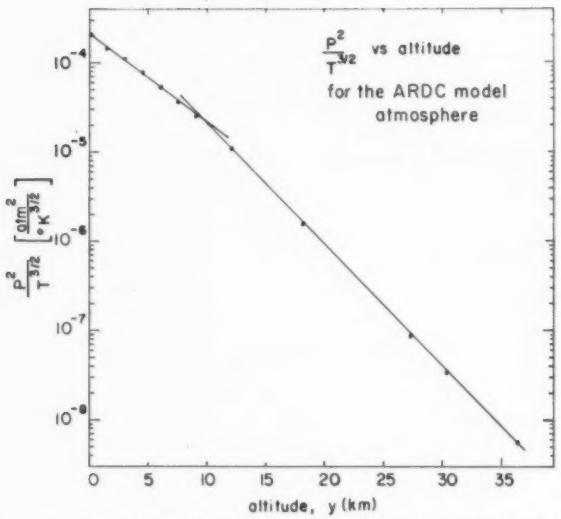

Fig. 1. Variation of $P^2/T^{3/2}$ with altitude for the 1959 ARDC model atmosphere.

lent path lengths and mean pressures for real paths. Zachor provides tables of values for doing so for his proposed summer and winter models of water vapor distribution.

III. Present Work

After a careful re-examination of the previous work it was concluded that the instances of poor fit in the work of Green and Downing were the combined result of (1) the breakdown of the formula when two species are absorbing with different n's and h's, and (2) the approximations used in the theoretical treatments which were the basis of the calculated transmission values.

The present work attempts to take fullest advantage of the prior work of Zachor, Carpenter *et al.*, and Howard *et al.* to arrive at a useful analytical equation which can cover most situations arising in practice. It was decided that the empirical fits for CO_2 absorption given by Zachor are the most reliable, and these have been used to determine an equation describing the carbon dioxide transmission through the atmosphere from any altitude, based on the method of Carpenter *et al.*

IV. Carbon Dioxide Vertical Transmission Model

Zachor gives four transmission models which will fit almost all the carbon dioxide data of Howard *et al.* at the discrete wavelengths analyzed between 1.03 μ and 10.8 μ. They are

$$T = 1 - \sinh\beta \int_0^y \exp(-y\cosh\beta)\, J_0(iy)dy, \qquad (1)$$

where $\beta = \beta_0(p/760)^c$ and $y = (s/d)(w/\sinh\beta)$,

$$T = 1 - \text{erf}\,(Kw^k p^{c/2}), \qquad (2)$$

$$T = [1 - \text{erf}\,(Kw^k p^{c/2})]^2, \qquad (3)$$

$$T = \exp(-Kw^k p^{c/2}). \qquad (4)$$

w is the optical thickness in atm-cm of CO_2 in the path and p is the mean pressure in mm Hg over the path.

Tables are provided showing which model to use at the particular wavelengths analyzed, and the values of K, k, $c/2$, s/d, and β_0 are given. The values of p and w may be calculated for any path from another set of tables.

The values of p and w given by Zachor are not used as there appear to be some inconsistencies in the method used in deriving them. In addition to this, no account is taken of temperature in determining the path length, w. This has been done by Carpenter *et al.* and their method is used here. This involves calculating a path length equivalent to laboratory conditions so that the value of p for Zachor's equations is fixed at 740 mm Hg.

It may be simply shown (e.g., ref. 2) that the vertical atmospheric path length, equivalent to laboratory conditions, is given approximately by

$$w = \int_{y_1}^{y_2} \frac{P}{P_s}\left(\frac{T_s}{T}\right)^{1/2} \rho dy, \qquad (5)$$

where P is the ambient atmospheric pressure (atm), T is the ambient air temperature (°K), P_s is the experimental pressure (0.974 atm), T_s is the experimental temperature (293°K), ρ is the density of the absorbing species at P and T in g/m³, and y is the altitude in km. Now

$$\rho = \frac{fMP}{RT}, \qquad (6)$$

where M is the molecular weight of CO_2 (44.01 g/mole), R is the gas constant (82.07 cc atm/mole deg), and f is

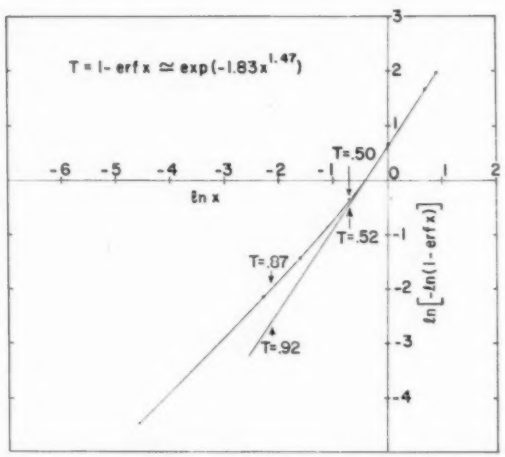

Fig. 2. Approximation of the error function absorption law to an exponential form.

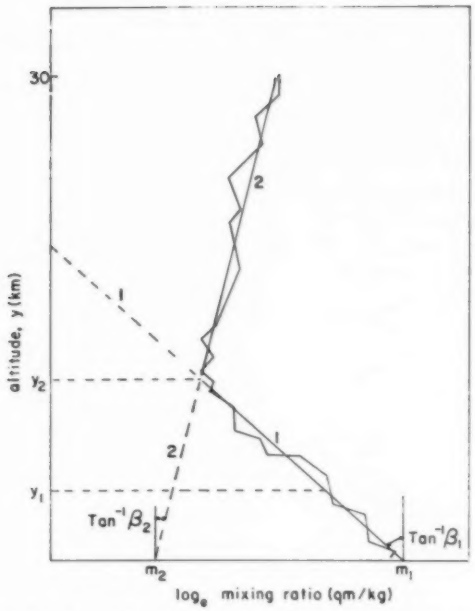

Fig. 3. Approximation to a real water vapor distribution.

the fractional concentration (by volume) of CO_2 (3.3×10^{-4}). Therefore

$$w = \frac{fMT_s^{1/2}}{RP_s} \int_{y_1}^{y_2} \frac{P^2}{T^{3/2}} dy \quad \text{g/cm}^2. \tag{7}$$

This may be integrated since $P^2/T^{3/2}$ approximately varies exponentially with altitude (see Fig. 1) up to about 35 km, which fortunately is the region of most interest, i.e.

$$\frac{P^2}{T^{3/2}} = Ae^{-\alpha y}. \tag{8}$$

Integrating from y to ∞:

$$w = \frac{fMT_s^{1/2}A}{RP_s\alpha} e^{-\alpha y} \quad \text{g/cm}^2$$

$$= \frac{509.4\, fMT_s^{1/2}A}{RP_s\alpha} e^{-\alpha y} \quad \text{atm-cm}. \tag{9}$$

But from Fig. 1,

$$\begin{aligned} P^2/T^{3/2} &= 4.96 \times 10^{-4} e^{-0.313y} \quad 8\text{–}35 \text{ km}, \\ P^2/T^{3/2} &= 2.15 \times 10^{-4} e^{-0.226y} \quad 0\text{–}8 \text{ km}. \end{aligned} \tag{10}$$

Thus we obtain for the equivalent path:

$$\begin{aligned} w &= 252e^{-0.313y} \quad 8\text{–}35 \text{ km}, \\ w &= 151e^{-0.226y} \quad 0\text{–}8 \text{ km}. \end{aligned} \tag{11}$$

These are the atmospheric path lengths equivalent to the laboratory conditions. When they are substituted into Zachor's equations, taking p as 740 mm Hg, we have in model (4)

$$T = \exp(-Ce^{-y/h}), \tag{12}$$

where

$$\begin{aligned} C &= K\,740^{c/2}\,252^k \text{ and } 1/h = 0.313k \quad 8\text{–}35 \text{ km}, \\ C &= K\,740^{c/2}\,151^k \text{ and } 1/h = 0.226k \quad 0\text{–}8 \text{ km}. \end{aligned} \tag{13}$$

Thus, given the value of C and h the transmission through the atmosphere in the carbon dioxide absorption bands can readily be calculated for any altitude. This same equation, to a close approximation, will describe the other models, since for the range of values of $Kw^kp^{c/2}$ ($=x$) used in this work (see Fig. 2)

$$1 - \operatorname{erf} x \doteq \exp(-1.83x^{1.47}). \tag{14}$$

It should be noted that the exponential form departs from the error function in the thin absorber region. This is where the error function becomes a poor approximation, and it is gratifying that the exponential form deviates in the right direction.

Using Eq. (14), model (2) takes on the form of Eq. (12) with

$$\begin{aligned} C &= 1.83\,K^{1.47}\,740^{1.47c/2}\,252^{1.47k} \text{ and } 1/h = 0.460k, \quad 8\text{–}35 \text{ km}, \\ C &= 1.83\,K^{1.47}\,740^{1.47c/2}\,151^{1.47k} \text{ and } 1/h = 0.332k \quad 0\text{–}8 \text{ km}, \end{aligned} \tag{15}$$

and model (3) has

$$\begin{aligned} C &= 3.66\,K^{1.47}\,740^{1.47c/2}\,252^{1.47k}\,1/h = 0.460k \quad 8\text{–}35 \text{ km}, \\ C &= 3.66\,K^{1.47}\,740^{1.47c/2}\,151^{1.47k}\,1/h = 0.332k \quad 0\text{–}8 \text{ km}. \end{aligned} \tag{16}$$

To express model (1) in the same form, the transmission is calculated according to model (1), and the values of $\ln(-\ln T)$ are plotted against altitude. The resulting straight line gives C and h from its intercept and slope.

The values of C and h at diserete wavelengths are given in Table I.

V. Water Vapor Vertical Transmission Model

Howard *et al.* fitted the Goody model to their water vapor absorption data and, obtained the following expression:

$$T = \exp - \frac{1.97w/w_0}{[1 + 6.57(w/w_0)]^{1/2}}, \tag{17}$$

where w is the optical thickness in precipitable centimeters of the water vapor path, and w_0 is the optical thickness of water vapor necessary to yield a transmission of 0.5 and is a function of wavelength and pressure. The expression may be simplified to the same form as we have for the CO_2 transmission model, since for the interesting range of transmission values, see Fig. 4:

$$\exp - \frac{1.97(w/w_0)}{[1 + 6.57(w/w_0)]^{1/2}} \doteq \exp\left(-0.64\left(\frac{w}{w_0}\right)^{0.55}\right). \tag{18}$$

The values of w_0 for the laboratory conditions have been tabulated by Zachor in a convenient form for the wave-

Table I. Values of Constants for the Transmission Equations at Wavelengths 1.03 μ to 10.80 μ

	CO_2					
	8–35 km		0–8 km			H_2O
λ	C	h	C	h	n	K
1.03	↑					3.7×10^{-3}
1.04	|					5.8×10^{-3}
1.05	$\tau \simeq 1$					9.0×10^{-3}
1.06	|					8.4×10^{-3}
1.07	|					2.5×10^{-2}
1.08	|					4.6×10^{-2}
1.09	|					7.7×10^{-2}
1.10	|					1.2×10^{-1}
1.11	|					1.8×10^{-1}
1.12	|					2.4×10^{-1}
1.13	|					2.8×10^{-1}
1.14	|					2.6×10^{-1}
1.15	|					2.0×10^{-1}
1.16	|					1.4×10^{-1}
1.17	|					1.0×10^{-1}
1.18	|					7.6×10^{-2}
1.19	|					5.4×10^{-2}
1.20	|					3.6×10^{-2}
1.21	|					2.2×10^{-2}
1.22	|					1.0×10^{-2}
1.23	|					5.6×10^{-3}
1.24	|					1.1×10^{-2}
1.25	|					1.9×10^{-2}
1.26	|					3.4×10^{-2}
1.27	|					5.7×10^{-2}
1.28	|					9.5×10^{-2}
1.29	|					1.5×10^{-1}
1.30	|					2.2×10^{-1}
1.31	|					3.4×10^{-1}
1.32	$\tau \simeq 1$					4.9×10^{-1}
1.33	|					7.0×10^{-1}
1.34	|					9.6×10^{-1}
1.35	|					1.3
1.36	↓					1.5
1.37	3.01×10^{-6}	4.3	2.07×10^{-5}	6.0	0.735	1.6
1.38	4.24×10^{-4}	4.3	2.91×10^{-4}	6.0	0.735	1.5
1.39	1.35×10^{-3}	4.3	9.23×10^{-4}	6.0	0.735	1.4
1.40	3.05×10^{-3}	4.3	2.10×10^{-3}	6.0	0.735	1.2
1.41	6.93×10^{-3}	4.3	4.75×10^{-3}	6.0	0.735	1.0
1.42	6.17×10^{-2}	8.0	5.03×10^{-2}	11.1	0.399	8.5×10^{-1}
1.44	6.38×10^{-2}	8.0	5.20×10^{-2}	11.1	0.399	5.4×10^{-1}
1.46	7.68×10^{-3}	4.3	5.27×10^{-3}	6.0	0.735	3.2×10^{-1}
1.48	2.21×10^{-3}	4.3	1.52×10^{-3}	6.0	0.735	2.0×10^{-1}
1.50	8.16×10^{-5}	4.3	5.60×10^{-5}	6.0	0.735	1.2×10^{-1}
1.52	4.65×10^{-6}	4.3	3.19×10^{-6}	6.0	0.735	7.4×10^{-2}
1.54	8.39×10^{-4}	4.3	5.76×10^{-4}	6.0	0.735	3.9×10^{-2}
1.56	4.41×10^{-3}	4.3	3.03×10^{-3}	6.0	0.735	3.7×10^{-3}
1.58	1.36×10^{-2}	4.3	9.34×10^{-3}	6.0	0.735	8.7×10^{-3}
1.60	5.95×10^{-2}	7.2	4.74×10^{-2}	9.9	0.446	3.8×10^{-2}
1.63	7.39×10^{-3}	4.3	5.07×10^{-3}	6.0	0.735	5.8×10^{-3}
1.65	3.13×10^{-3}	4.3	2.15×10^{-3}	6.0	0.735	5.5×10^{-3}
1.67	7.03×10^{-4}	4.3	4.83×10^{-4}	6.0	0.735	1.8×10^{-2}
1.68	1.18×10^{-4}	4.3	8.11×10^{-5}	6.0	0.735	2.4×10^{-2}
1.69	↑					3.2×10^{-2}
1.70	|					4.4×10^{-2}
1.72	$\tau \simeq 1$					8.2×10^{-2}
1.74	|					1.5×10^{-1}
1.76	|					2.9×10^{-1}
1.78	|					5.4×10^{-1}

Table I (continued)

	CO_2					
	8–35 km		0–8 km			
λ	C	h	C	h	n	H_2O K
1.80	$\tau \simeq 1$					
1.82	↓					9.5×10^{-1}
1.84						1.6
1.86						2.5
1.88						2.7
1.90	2.95×10^{-3}	4.3	2.03×10^{-3}	6.0	0.735	2.0
1.92	2.20×10^{-2}	4.3	1.51×10^{-2}	6.0	0.735	1.3
1.94	1.09×10^{-1}	4.3	7.47×10^{-2}	6.0	0.735	7.7×10^{-1}
1.95	2.29×10^{-1}	4.7	1.62×10^{-1}	6.5	0.676	4.7×10^{-1}
1.96	2.58×10^{-1}	4.3	1.77×10^{-1}	6.0	0.735	3.7×10^{-1}
1.97	1.63×10^{-1}	4.1	1.09×10^{-1}	5.7	0.776	2.8×10^{-1}
1.98	1.21×10^{-1}	4.3	8.33×10^{-2}	6.0	0.735	2.2×10^{-1}
1.99	1.00×10^{-1}	3.2	6.03×10^{-2}	4.5	0.993	1.7×10^{-1}
2.00	4.22×10^{-1}	4.5	2.92×10^{-1}	6.2	0.717	1.3×10^{-1}
2.01	8.79×10^{-1}	7.2	7.00×10^{-1}	9.9	0.446	1.0×10^{-1}
2.02	6.15×10^{-1}	8.9	5.12×10^{-1}	12.4	0.358	8.0×10^{-2}
2.03	3.60×10^{-1}	7.1	2.86×10^{-1}	9.9	0.447	6.3×10^{-2}
2.04	1.66×10^{-1}	4.3	1.14×10^{-1}	6.0	0.735	4.9×10^{-2}
2.05	2.19×10^{-1}	4.3	1.50×10^{-1}	6.0	0.735	3.9×10^{-2}
2.06	2.97×10^{-1}	4.3	1.97×10^{-1}	6.0	0.735	3.1×10^{-2}
2.07	2.63×10^{-1}	5.2	1.93×10^{-1}	7.3	0.610	2.5×10^{-2}
2.08	2.25×10^{-1}	8.0	1.83×10^{-1}	11.1	0.399	2.1×10^{-2}
2.10	3.78×10^{-4}	4.3	2.60×10^{-4}	6.0	0.735	1.7×10^{-2}
2.12	↑					1.1×10^{-2}
2.14	$\tau \simeq 1$					7.9×10^{-3}
2.16	↓					5.7×10^{-3}
2.18						4.3×10^{-3}
2.20						5.0×10^{-3}
2.24	$\tau \simeq 1$					6.9×10^{-3}
2.28						1.6×10^{-2}
2.32						3.4×10^{-2}
2.36						7.0×10^{-2}
2.40						1.3×10^{-1}
2.44						2.3×10^{-1}
2.48						4.1×10^{-1}
2.52						1.4
2.54						1.8
2.56						2.7
2.58						4.0
2.60						4.6
2.62						5.1
2.64	2.02×10^{-1}	7.2	1.60×10^{-1}	9.9	0.446	5.8
2.66	8.85×10^{-1}	8.5	7.31×10^{-1}	11.8	0.375	7.2
2.68	3.34	7.1	2.66	9.9	0.448	8.9
2.70	6.86	7.2	5.46	9.9	0.446	9.8
2.72	4.71	7.7	3.81	10.7	0.414	9.3
2.74	4.41	6.4	3.41	8.8	0.500	6.4
2.76	13.30	4.4	9.14	6.0	0.735	4.8
2.78	7.36	6.4	5.69	8.8	0.500	4.3
2.80	3.23	8.0	2.63	11.1	0.399	4.0
2.82	1.50	10.9	1.29	15.2	0.292	3.7
2.84	5.86×10^{-1}	14.8	5.25×10^{-1}	20.5	0.216	3.2
2.86	2.68×10^{-1}	16.9	2.44×10^{-1}	23.4	0.189	2.6
2.88	1.13×10^{-1}	10.9	9.74×10^{-2}	15.2	0.292	2.0
						1.5

Table I (continued)

	CO_2					
	8–35 km		0–8 km			
λ	C	h	C	h	n	H_2O K
2.90						1.1
2.92						7.6×10^{-1}
2.94						6.5×10^{-1}
2.96						5.9×10^{-1}
2.98	$\tau \simeq 1$					5.8×10^{-1}
3.00						5.7×10^{-1}
3.02						5.9×10^{-1}
3.04						6.3×10^{-1}
3.06						6.6×10^{-1}
3.08						6.6×10^{-1}
3.10						5.9×10^{-1}
3.12						4.4×10^{-1}
3.14						3.0×10^{-1}
3.16						2.5×10^{-1}
3.18						3.4×10^{-1}
3.20						1.9×10^{-1}
3.22						1.5×10^{-1}
3.24						1.5×10^{-1}
3.26						1.7×10^{-1}
3.28						1.9×10^{-1}
3.30						2.2×10^{-1}
3.32						2.5×10^{-1}
3.34						2.9×10^{-1}
3.36						3.4×10^{-1}
3.40						2.4×10^{-1}
3.44						1.7×10^{-1}
3.48						1.2×10^{-1}
3.52						1.2×10^{-1}
3.56						6.0×10^{-2}
3.60						4.2×10^{-2}
3.64						2.9×10^{-2}
3.68	$\tau \simeq 1$					2.1×10^{-2}
3.72						1.5×10^{-2}
3.76						1.0×10^{-2}
3.80						7.3×10^{-3}
3.84						5.2×10^{-3}
3.88						3.7×10^{-3}
3.92						2.6×10^{-3}
3.96						
4.05	4.16×10^{-2}	4.3	2.85×10^{-2}	6.0	0.735	
4.10	3.20×10^{-2}	3.9	1.90×10^{-2}	5.7	0.735	
4.15	8.30×10^{-2}	5.5	6.10×10^{-2}	7.6	0.735	$\tau \simeq 1$
4.20	8.29	4.3	5.69	6.0	0.735	
4.35	15.40	7.2	12.26	9.9	0.446	
4.40	8.63	6.4	6.68	8.5	0.500	3.4×10^{-3}
4.45	3.46	6.4	2.68	8.5	0.500	5.5×10^{-3}
4.50	1.13	3.7	6.50×10^{-1}	5.7	0.735	8.6×10^{-3}
4.55	4.81×10^{-2}	4.3	3.30×10^{-2}	6.0	0.735	1.3×10^{-2}
4.60	2.13×10^{-2}	4.3	1.46×10^{-2}	6.0	0.735	1.9×10^{-2}
4.65	1.53×10^{-2}	4.3	1.05×10^{-2}	6.0	0.735	2.9×10^{-2}
4.70	4.07×10^{-2}	4.3	2.80×10^{-2}	6.0	0.735	4.1×10^{-2}
4.75	1.70×10^{-1}	4.0	1.10×10^{-1}	6.2	0.735	6.0×10^{-2}
4.80	3.90×10^{-1}	3.6	2.20×10^{-1}	5.6	0.735	8.6×10^{-2}
4.85	5.60×10^{-1}	4.0	3.1×10^{-1}	6.5	0.735	1.2×10^{-1}
4.90	1.8×10^{-1}	5.5	1.4×10^{-1}	6.5	0.735	1.5×10^{-1}

Table I (continued)

	CO_2					
	8–35 km		0–8 km			
λ	C	h	C	h	n	H_2O K
4.95	↑					
5.05	$\tau \simeq 1$					2.0×10^{-1}
5.10	|					3.0×10^{-1}
5.15	|					3.6×10^{-1}
5.20	|					4.3×10^{-1}
5.25	|					5.1×10^{-1}
5.35	$\tau \simeq 1$					6.1×10^{-1}
5.40	|					8.7×10^{-1}
5.45	|					1.1
5.50	|					1.3
5.60	|					1.5
5.70	|					2.3
5.80	|					3.5
5.85	|					5.1
5.90	|					6.1
5.95	|					7.6
6.00	|					8.8
6.05	|					1.0×10
6.10	|					1.0×10
6.15	|					9.9
6.20	|					8.3
6.25	|					6.9
6.30	|					5.7
6.35	|					4.9
6.40	|					4.8
6.45	|					5.1
6.50	|					6.3
6.55	|					8.1
6.60	|					1.0×10
6.65	|					1.2×10
6.70	|					1.3×10
6.75	|					1.3×10
6.80	|					1.2×10
6.85	$\tau \simeq 1$					1.1×10
6.90	|					9.8
6.95	|					8.6
7.00	|					7.6
7.10	|					6.7
7.20	|					5.2
7.40	|					4.0
7.60	|					2.4
7.80	|					1.4
8.00	|					8.4×10^{-2}
8.20	|					5.1×10^{-1}
8.40	|					3.4×10^{-1}
8.60	|					2.3×10^{-1}
8.80	|					1.6×10^{-1}
9.00	|					1.2×10^{-1}
9.20	|					8.5×10^{-2}
9.40	|					6.2×10^{-2}
9.60	|					4.5×10^{-2}
9.80	|					3.1×10^{-2}
10.00	|					2.2×10^{-2}
10.20	|					1.5×10^{-2}
10.40	|					9.5×10^{-3}
10.60	|					5.7×10^{-3}
10.80	↓					3.2×10^{-3}
						$\tau \simeq 1$

lengths under consideration, and Carpenter *et al.* give a method for determining the path length w, equivalent to the laboratory conditions, for vertical transmission in the 1956 ARDC Model Atmosphere in which the water vapor mixing ratio is constant with height.

VI. Equivalent Path Lengths for Nonconstant Mixing Ratio

The equivalent path length is to be calculated by a method similar to that of Carpenter *et al.* for a water vapor distribution in which the mixing ratio varies exponentially with height. The distribution is defined by the parameters m and β (see Fig. 3), i.e.,

$$(mr) = me^{\beta y}. \tag{19}$$

Following the same procedure as we used to find the equivalent path length for carbon dioxide we have

$$w = \int_{y_1}^{y_2} \frac{P}{P_s}\left(\frac{T_s}{T}\right)^{1/2} \rho dy, \tag{5}$$

where now $\rho = 10^{-3}(mr)MP/RT$, (mr) is the mixing ratio in g/kg, and M is the molecular weight of air (28.97 g/mole). Therefore

$$\begin{aligned} w &= \frac{10^{-3} m\, MT_s^{1/2}}{RP_s}\int_y^\infty \frac{P^2}{T^{3/2}} e^{\beta y} dy \qquad \text{in pr km,} \\ &= \frac{10^3\, m\, MT_s^{1/2} A}{RP_s(\alpha - \beta)} e^{(\beta - \alpha)y} \qquad \text{pr cm.} \end{aligned} \tag{20}$$

So we obtain for the equivalent path for water vapor:

$$\begin{aligned} w &= \frac{0.308\, m}{(0.313 - \beta)} e^{(\beta - 0.313)y} \qquad 8\text{–}35 \text{ km,} \\ w &= \frac{0.133\, m}{(0.226 - \beta)} e^{(\beta - 0.226)y} \qquad 0\text{–}8 \text{ km.} \end{aligned} \tag{21}$$

These expressions are substituted into Eq. (18) to obtain the vertical transmission model for the water vapor absorption bands:

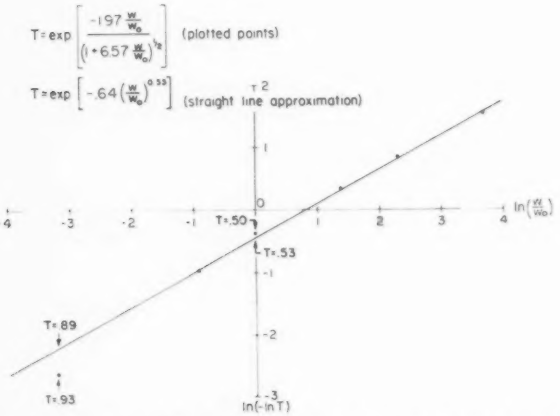

Fig. 4. Approximation to the Howard *et al.* fit to the Goody model of water vapor absorption.

Table II. Values of the Chapman Function Used in the Transmission Equations

θ	$f(800, \theta)$	θ	$f(800, \theta)$	θ	$f(800, \theta)$	θ	$f(800, \theta)$
20	1.064	39	1.286	57	1.831	75	3.800
21	1.071	40	1.304	58	1.881	76	4.055
22	1.078	41	1.324	59	1.935	77	4.348
23	1.086	42	1.344	60	1.993	78	4.687
24	1.094	43	1.366	61	2.054	79	5.083
25	1.103	44	1.388	62	2.121	80	5.551
26	1.112	45	1.412	63	2.192	81	6.113
27	1.122	46	1.438	64	2.269	82	6.799
28	1.132	47	1.464	65	2.353	83	7.650
29	1.143	48	1.492	66	2.443	84	8.732
30	1.154	49	1.522	67	2.542	85	10.144
31	1.166	50	1.553	68	2.650	86	12.051
32	1.179	51	1.586	69	2.767	87	14.730
33	1.192	52	1.621	70	2.897	88	18.686
34	1.206	53	1.658	71	3.040	89	24.905
35	1.220	54	1.697	72	3.199	90	35.466
36	1.235	55	1.739	73	3.376	91	55.211
37	1.251	56	1.783	74	3.575	92	96.753
38	1.268						

$$\begin{aligned} T &= \exp -\left(\frac{Km^{0.55}}{(0.313 - \beta)^{0.55}} e^{0.55(\beta - 0.313)y}\right) \qquad 8\text{–}35 \text{ km,} \\ T &= \exp -\left(\frac{0.630\, Km^{0.55}}{(0.226 - \beta)^{0.55}} e^{0.55(\beta - 0.226)y}\right) \qquad 0\text{–}8 \text{ km,} \end{aligned} \tag{22}$$

where $K = 0.337/w_0^{0.55}$. The values of K are tabulated alongside the constants for carbon dioxide transmission.

There is a mathematical limitation to the use of these equations, since β must be less than 0.226 below 8 km, and less than 0.313 above 8 km. This is not a practical limitation as β does not exceed these values for any great depth in a real atmosphere.

VII. Slant Paths

For nonvertical paths at angle θ to the vertical the path length is multiplied by secant θ, if the earth may be considered flat. This is reasonably accurate up to $\theta = 80°$ for a curved earth, but is unacceptable for larger angles. Graphical methods have been used to determine path lengths at large angles but are tedious to apply. A simple method due to Chapman[7] overcomes this difficulty. He is concerned with the formation of the ionosphere and assumes that the density of the air, which is the absorbing species in his case, varies exponentially with height. Thus his work is directly applicable to the carbon dioxide absorption, and is probably good for the water vapor absorption. Chapman deduces a function which replaces secant θ:

$$f(x, \theta) = x \sin\theta \int_0^\theta \exp(x - x \sin\theta/\sin\phi)\operatorname{cosec}^2\phi d\phi, \tag{23}$$

where $x = (\alpha + h)/H$, α is the radius of earth, h is the height above surface of earth, and H is the scale height.

The function does not vary much as x becomes large, and for the altitudes of interest in the present work

$x = 800$ is used. Values of $f(800, \theta)$, determined by Wilkes,[8] are given in Table II. One can show that up to $\theta = 35°$, $f(800, \theta)$ very accurately approximates secant θ, and up to 80° it approximates secant θ fairly well.

Thus using the Chapman function for slant paths we have the final absorption models:

$$CO_2 \; T = \exp[-Ce^{-y/h} f^n(800, \theta)], \tag{24}$$

where n is 0.735 for model (1), n is $1.47k$ for models (2) and (3), and n is k for model (4).

$$H_2O, \quad T = \exp\left(\frac{-Km^{0.55}}{(0.313 - \beta)^{0.55}} e^{0.55(\beta - 0.313)y} f^{0.55}(800,\theta)\right) \quad 8\text{–}35 \text{ km}, \tag{25}$$

$$T = \exp\left(\frac{-0.630Km^{0.55}}{(0.226 - \beta)^{0.55}} e^{0.55(\beta - 0.226)y} f^{0.55}(800,\theta)\right) \quad 0\text{–}8 \text{ km}.$$

VIII. Use of the Water Vapor Model with a Real Atmosphere

A good approximation to actual water vapor distributions in the atmosphere can generally be made by dividing the atmosphere into layers in which the mixing ratio varies exponentially with height. With a little smoothing, two layers often suffice (see Fig. 3). The distribution above 30 km is not considered, as its effect on the transmission at lower levels is negligible due to the low air density above 30 km.

The real distribution may then be approximated by combining two layers in which the mixing ratio varies exponentially with altitude, taking one from each of the distributions, 1 and 2.

Now the transmission from altitude y_1 in the lower layer through the atmosphere to infinity for the approximated real distribution is given by:

$$T(y_1 \infty, 1, 2) = T(y_2 \infty, 2)\, T(y_1 y_2, 1). \tag{26}$$

The transmission from y_1 to y_2 for distribution 1 is simply:

$$T(y_1 y_2, 1) = \frac{T(y_1 \infty, 1)}{T(y_2 \infty, 1)}.$$

Therefore

$$T(y_1 \infty, 1, 2) = T(y_2 \infty, 2) \quad \frac{T(y_1 \infty, 1)}{T(y_2 \infty, 1)}. \tag{27}$$

Thus the water vapor transmission through the two-layer approximation is described in terms of the model. This method could be extended to a distribution with more layers but the expressions would be very complex, and there is little loss in useful accuracy in using the two layer approximation.

Of course, if the altitude being considered is in the upper layer, then the transmission is given directly by the model.

To obtain the transmission through the atmosphere, taking into account both carbon dioxide and water vapor absorption, the values of transmission given by the models are multiplied together:

$$T_{\text{total}} = T_{CO_2} \times T_{H_2O}. \tag{28}$$

IX. Use of Constants for Absorption over a Band

The constants given in Table I are for discrete wavelengths, and, to obtain the mean transmission over a complete band, the transmission curve determined by the values calculated at the discrete wavelengths must be drawn, and the mean transmission found graphically. The transmission is not generally required over a complete band but only over a small bandwidth, and the mean transmission may be determined quite rapidly.

X. Discussion and Conclusion

The values of the constants have been derived from empirical fits to laboratory low-resolution spectra. To date, there is, to the knowledge of the authors, no data obtained in the atmosphere suitable for checking the validity of the transmission models and for determining the values of the constants.

The possibilities of balloon-borne experiments to determine the values of the constants are now being investigated.

In this work we have in effect taken various semiempirical analytical expressions for absorption as a function of optical path and pressure, and combined them with a semiempirical analytical expression for optical path in terms of height and slant angle. A feature of the final expressions is that they include two parameters which characterize water vapor distributions occurring in the atmosphere.

The combined analytic function in certain wavelength ranges has been modified somewhat to be uniform form for all cases. Of course, we might have used the analytic form for path lengths in conjunction with the various separate analytical or tabular forms of transmission in terms of w. However, it is our belief that the over-all uncertainties in theory and in experiment at this time are such that this complication is not warranted.

Extension of this work to include absorption by ozone and other species has been started.

The writers wish to express their appreciation to J. A. L. Thomson for many helpful discussions, to M. Downing for assistance in the early phases of this work, and to W. A. Elsasser for a helpful review. In addition, the writers would like to thank A. S. Zachor for providing a preprint of his report which greatly accelerated this initial assignment of the parameters for our final analytical formula.

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Meeting Reports

VI International Congress on High-Speed Photography, September 15–22, 1962, Scheveningen, The Netherlands

Reported by Harold E. Edgerton, MIT

The VI International Congress on High-Speed Photography completed its formal sessions on Saturday, September 22 at 12:30 p.m. after a full week of papers and discussions. The official program listed 99 papers to be presented from 8:30 a.m. until 9 p.m. on most days. "Time out" was allowed for a half day, in order to watch the colorful opening of the Dutch Parliament by the Queen, and for a full day of sight-seeing in scenic Holland.

The tight schedule of papers was held to time by an automatic green-yellow-red timing light with attention-making noises at the end of allotted time. Nearly all authors kept to the schedule. There were remarks by some attendees regarding the lack of active discussion on the papers, due to this time scheduling problem and to the large attendance at the Congress. Some 350 people were registered from at least 20 countries. Pressure was put on the delegates that presented papers to submit their results for publication in a volume that is scheduled for printing in the near future by H. D. Tjeenk Willink & Zn, Haarlem, Nederland.

The official opening ceremony was a formal affair where state and civil officials made statements to welcome us to Holland and it must be said that every effort was expended to extend full hospitality to us. We left with a feeling of good will and thankfulness to our hosts. H. W. Julius opened the technical exhibit at noon of the first day with a ceremony which included a sudden unveiling of a series of milk drop photographs and the flashing of lights. The theme photo of the exhibit was the crown-shaped milk drop splash on a plate covered by a thin layer of milk.

The technical sessions began with a keynote address by Hubert Schardin on the possibilities and limits of high-speed photography, and no one more qualified could have been selected than Dr. Schardin. In addition to his contributions to the practice of high-speed photography, he has been in the forefront of theory. He filled his allotted time with high-speed talk full of information theory regarding the evaluation of the many different types of high-speed photography systems now in use or contemplated. A mathematical relationship containing both space resolution and time resolution of high-speed photography was derived. He then demonstrated how his analysis could be applied to some of the many systems of photography that are now in use. Of particular interest was his conclusion that the information content was often increased by the use of a larger photographic area than that of a smaller photograph at a higher time rate of photography.

A list of the sessions is symbolic of the material presented during the session: Cameras, Cameras and Shutters, Cameras and Light Sources, Kerr-cells and Intensifiers, Light Sources, Kerr-cells and Sensitive Materials, Flash X-Ray, Instrument Aids, Applications, Shock Waves, Miscellaneous, and Explosives.

Of special interest to this reporter were the sessions on light sources. Seven papers were listed in the program, covering possible use of laser pulses, xenon-flash-lamps with large output for laser stimulation, sparks in many kinds of gases and at several pressures, low-inductance spark exciting circuits, semiconductor spark ignition circuits, and piezoelectrically charged capacitor systems for operating short-duration sparks. In addition, there was a thread of background material about lights in the discussions of cameras and applications.

Immanuel Marshak from the Moscow Electric Lamp Works presented a nonscheduled paper which described the application of xenon lamps for high-power continuous light sources such as are needed for high-speed photography. He stated that 100 kW of electrical power had been put into water-cooled lamps of 1.2-cm diameter, 143 cm long, on 380 V. No resistive or inductive elements were used to stabilize the arc since these long lamps have a positive volt-ampere characteristic. Dr. Marshak mentioned efficiencies up to 50 lumens per watt and pointed out that much larger lamps were possible. Perhaps I was mistaken when I heard him say that a lamp with more than 1500 kW had already been tried? Even the 100-kW lamp is an accomplishment. He also gave operational information concerning powerful pulsed lamps with 1-sec operating time. Such sources are useful for taking high-speed photographs.

The possible use of lasers for high-speed photography was discussed by Drs. Früngel and Patzske from Germany. The authors showed the microsecond output pulses of red light that are emitted by the ruby laser, and how they might be employed to take a series of short-exposure photographs at a high rate on a moving film. No examples of photography were seen.

Frommhold and Raether reported on the output of a low-inductance capacitor of 1000 pF at 7 kV into several gases at different pressures. They concluded that ether vapor was the best to produce a 10 nsec (half-peak) pulse of light followed by the usual tail. Then a Kerr cell with chloroform and nicol prisms was used to cut off the tail but also to permit the transmission of radiation down to 2500 Å. The final result was an ultraviolet pulse of 9 nsec half-width duration without the characteristic tail.

The performance of the conventional high-pressure xenon flash lamp, under overloaded conditions as encounted in laser stimulation, was presented by Goncz with coauthors Jameson and

continued on page 603

The 15–26 Micron Sky Emission Spectrum at Jungfraujoch (3570 m)

H. J. Bolle

The sky emission between 15 and 26 μ has been measured at the Jungfraujoch (alt. 3570 m) using a grating spectrometer with high resolution. Absorption coefficients have been determined for window regions between water vapor rotational lines. The emissivity of cirrus clouds could be estimated from assumed cloud temperatures and measured cloud emission.

I. Instrumentation

For spectral investigations of the infrared sky emission a portable grating spectrometer with Czerny-Turner mounting[1] has been constructed. It equals in principle the instrument which Goody[2] used in 1957 for sky emission measurements. However, a mirror system in front of the entrance slit makes the spectrometer an absolutely symmetrical double-beam instrument with detector output proportional to the difference in the radiances of the two channels. The radiation in one of the channels originates in a reference blackbody, the other in the investigated source, e.g., sky or ground. The two radiances are combined after either passing the chopper or being reflected from it.

The reference blackbody is not a liquid nitrogen source as used by Roach and Goody[3] or Sloan *et al.*,[4] but a temperature-controlled black cavity well above air temperature. The spectrometer is calibrated by means of a second blackbody, which has to be cooler than the reference blackbody. The calibration procedure is similar to that used by Oetjen *et al.*[5]

The spectrometer and the calibration procedure have been previously described[6,7] and additional details have been reported in subsequent publications.[8,9]

II. Second-Order Overlapping Effects Between 24 and 26 μ

For use in the 15–26 μ region the spectrometer is equipped with a 15 × 15 cm² Merton grating (480 grooves per cm). Higher orders are removed by a bloomed indium antimonide filter and a lithium fluoride reststrahlen plate, which is mounted between the grating and the exit slit and tilted 45° to the optical path. The LiF reststrahlen plate does not have a completely sharp cutoff at 13 μ, but the transmission of the spectrometer at shorter wavelengths is small (Fig. 1). However, second-order overlapping does have to be taken into account between 24 and 26 μ. The amount of overlapping can be estimated by the following consideration: At a wavelength λ, 24 $\mu < \lambda < 26$ μ, the recorder deflection A_λ consists of two components: A_{λ_1} (12 $\mu < \lambda_1 <$ 13 μ) and A_{λ_2} (24 $\mu < \lambda < 26$ μ). In the case of the measurement of sky radiation:

$$A_{\lambda_i} = CD_{\lambda_i}\,[B(\lambda_i,T_s) - B(\lambda_i)]. \tag{1a}$$

The deflection $\tilde{A}_{\lambda_i}$ in the case of calibration is given by

$$\tilde{A}_{\lambda_i} = CD_{\lambda_i}\,[B(\lambda_i,T_1) - B(\lambda_i,T_2)], \tag{1b}$$

where the index i refers to either wavelength λ_1 or λ_2, C = calibration constant, D_{λ_i} = relative spectrometer transmissivity, $B(\lambda_i,T)$ = blackbody radiances, T_1 = temperature of reference blackbody, T_2 = temperature of calibration blackbody, $B(\lambda_i)$ = sky radiance.

The sky emission, $B(\lambda_2)$, is the quantity to be determined. From Eq. (1a)

$$B(\lambda_2) = B(\lambda_2,T_1) - \frac{A_{\lambda_2}}{CD_{\lambda_2}}. \tag{2}$$

But, if the overlapping effect is neglected, the quantity

$$B^*(\lambda_2) = B(\lambda_2,T_1) - \frac{A^*_\lambda}{CD^*_{\lambda_2}}, \tag{3}$$

is calculated from the records, with $A^*_{\lambda_2} = A_{\lambda_1} + A_{\lambda_2}$ and $D^*_{\lambda_2}$ = relative transmissivity of the spectrometer, with overlapping neglected.

If $CD^*_{\lambda_2}$ and CD_{λ_2} are determined from Eq. (1b) and the similar equation with asterisks (*), then from Eqs. (2) and (3), it follows that

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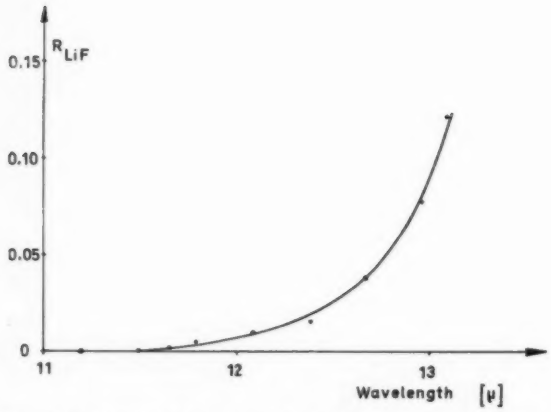


Fig. 1. Reflectivity of LiF reststrahlen plate (11–13.1 μ), measured as ratio of recorder deflection when the spectrometer is used with and without LiF plate in connection with a grating for 10-μ region.

$$B(\lambda_2) - B^*(\lambda_2) = \frac{A^*_{\lambda_2}}{\tilde{A}^*_{\lambda_2}} - \frac{A^*_{\lambda_2} - A_{\lambda_1}}{\tilde{A}^*_{\lambda_2} - \tilde{A}_{\lambda_1}} [B(\lambda_2, T_1) - B(\lambda_2, T_2)]. \quad (4)$$

In this equation only the quantities A_{λ_1} and $\tilde{A}_{\lambda_1}$ are unknown. They can be estimated using the Eq. (1a) for $i = 1$, setting $D_{\lambda_1} = (TR_{\mathrm{LiF}})_{\lambda_1}$, where T is the second-order spectrometer transmissivity without the reststrahlen plate, and R_{LiF} is the reflectivity of the LiF reststrahlen plate.

The transmissivity T could be estimated from a second-order laboratory spectrum taken with a blackbody source of about 500°K for $\lambda = 13.75\ \mu$ and $\lambda = 13.25\ \mu$, where $A_{\lambda_1} \gg A_{\lambda_2}$ (see e.g., Fig. 2). A reliable value for the 13-μ region is $T = 0.15$, which can also be accepted for 12.4 μ. Figure 1 shows that $R_{\mathrm{LiF}} = 0.02$ for $\lambda = 12.4\ \mu$. So $D_{13.4\mu} \cong 0.003$. With this value it follows from Eq. (4) for some examples of zenith measurements

$$B(24.8\ \mu) - B^*(24.8\ \mu) \cong 0.04\ \mathrm{W\ cm^{-2}sr^{-1}}. \quad (5)$$

The sky emission $B(\lambda_1)$ is very small at $\lambda = 12.4\ \mu$, therefore it has been neglected in this calculation.

Because B^* (24.8 μ, zenith) $\cong 0.4\ \mathrm{W\ cm^{-2}sr^{-1}}$ (see Fig. 3), the probable error of the sky emission measurement near 25 μ due to overlapping effects is of the order of about -10% of the measured value. The error becomes smaller if A_{λ_2} decreases, that is, if the sky emission increases.

III. Solar and Laboratory Spectra

In order to get a more detailed insight into the structure of the atmospheric spectrum and the second-order overlapping effect than can be obtained from emission measurements alone, some laboratory spectra and a solar spectrum have been recorded with a somewhat higher resolution than is used in emission work. In Fig. 2 original records of three spectra are reproduced: a section of the solar spectrum, a laboratory spectrum, and a zenith emission spectrum. The marked lines have been identified by the atlas of Migeotte *et al.*[10] and the laboratory water vapor spectrum of Randall.[11] The effect of second-order overlapping is very clearly to be seen in the solar spectrum, where second-order lines are marked with small letters, and in the laboratory spectrum beyond 25 μ. In the solar spectrum the ratio $B(12.5\ \mu)/B(25\ \mu)$ is 16 times larger than in the case of sky emission. Therefore, overlapping is much stronger in the solar spectrum than in emission spectra.

All identified lines with $\lambda > 19.0\ \mu$ belong to the water vapor rotational spectrum. Between 17.6 and 19.0 μ some water vapor lines have weak CO_2 and N_2O lines superimposed on them (see ref. 10). Identifications for lines resolved in emission spectra with $\lambda < 17.6\ \mu$ are listed in Table I. The two lines at 24.07 and

Table 1. Spectral Lines Identified in the 16–17.6 μ Sky Emission Spectrum

No.[a]	$\lambda[\mu]$	$\nu[\mathrm{cm^{-1}}]$	Identification[b]
1.	16.0208	624.02	CO_2, $C^{13}O_2^{16}$
4.	16.2035	619.98	CO_2, H_2O
6.	16.3647	610.90	N_2O, CO_2
8.	16.4474/0.4566	607.83/07.49	CO_2, N_2O
10.	16.5341	604.65	N_2O, CO_2, H_2O
13.	16.6603	600.07	N_2O, H_2O, CO_2
15.	16.7496	596.87	CO_2, N_2O
16.	16.7985	595.13	N_2O, CO_2, H_2O
18.	16.8913	591.86	N_2O, CO_2, H_2O
19.	16.9690	589.15	N_2O, CO_2
22.	17.0981	584.70	H_2O, CO_2, N_2O
24.	17.2111	580.86	CO_2, N_2O, H_2O
27.	17.3536	576.09	CO_2, N_2O, H_2O
30.	17.5009	571.24	CO_2, H_2O, N_2O
31.	17.5614	569.24	CO_2, N_2O, H_2O
32.	17.6264	567.18	H_2O, N_2O, CO_2

[a] Numbers refer to a Jungfraujoch solar spectrum recorded with better resolution.

[b] Identification as given in ref. 10. Principal constituent underlined.

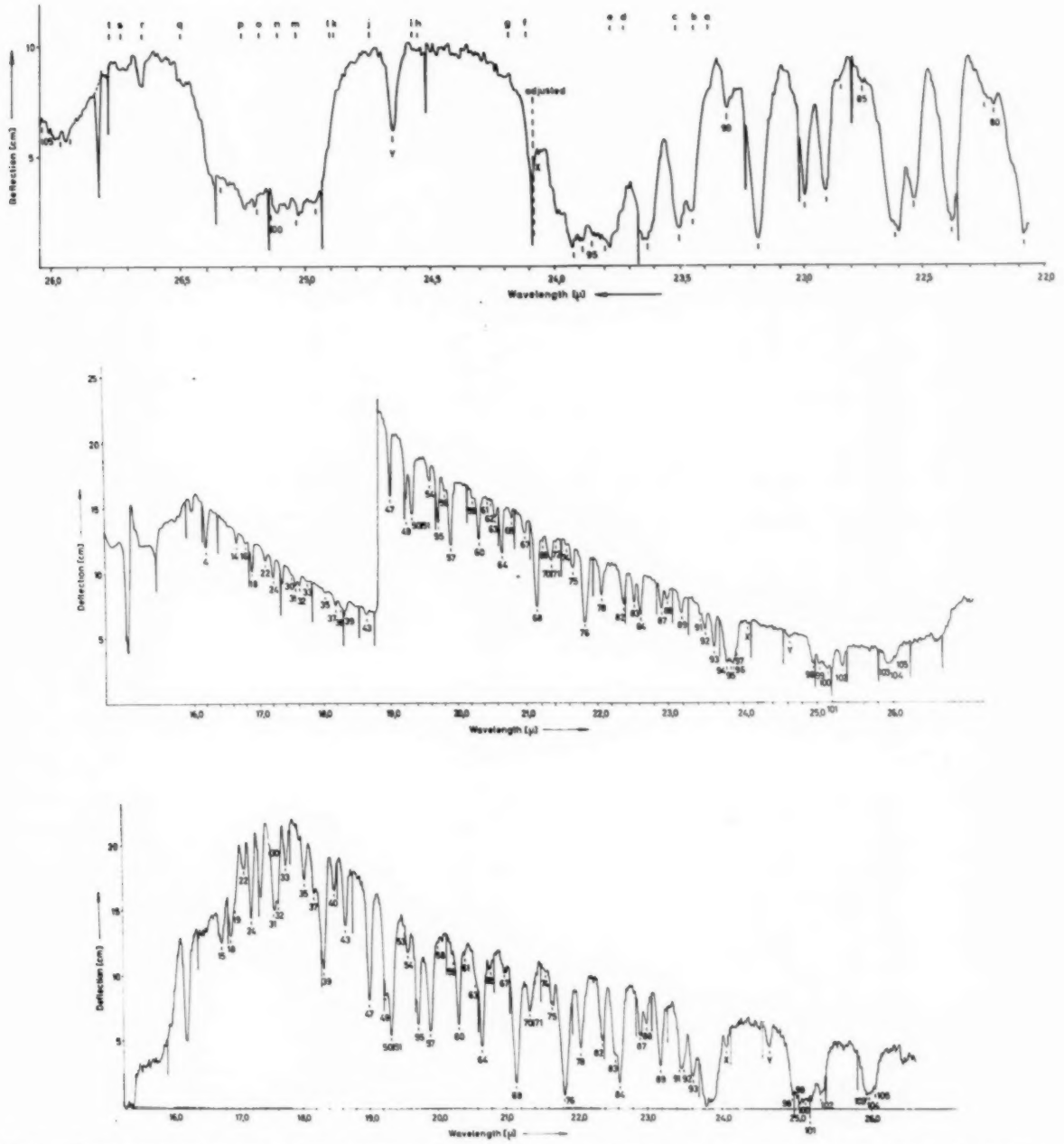
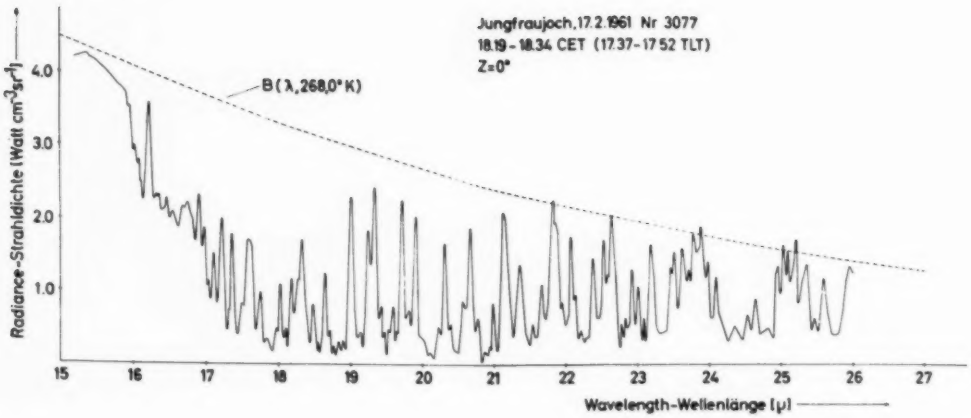


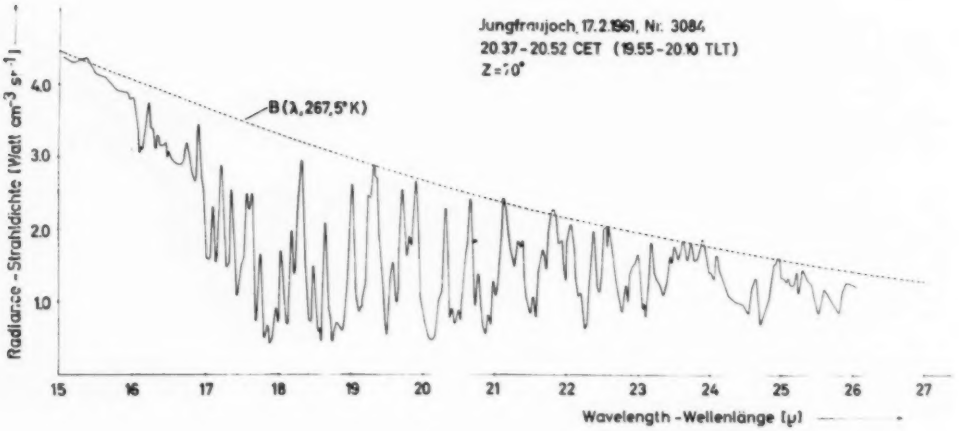
Fig. 2. Upper spectrum: Section of a solar spectrum taken on 17 February, 1961 from Jungfraujoch under a zenith angle which corresponds to two air masses. Slit width is 1 mm. Deflections are not proportional to true energy curve. Total amount of ppt. H_2O in optical path: ~0.12 cm. Amplifier gain altered at 18 μ. Middle spectrum: Laboratory spectrum with ~500°K source taken in München. Slit width 1.5 mm. Optical path between source and detector about 5 m. Lower spectrum: Zenith emission spectrum on 17 February, 1961 at Jungfraujoch (p = 666.8 mb). Slit width 2.5 mm. Total amount of ppt. H_2O: 0.085 cm. Numbered lines are identified by refs. 10 and 11, lines marked with small letters are second-order lines of the 12–13 μ region. X and Y are unidentified lines.

24.65 μ could not definitely be identified. The line at 24.65 μ is also present in the water vapor spectra of Palmer.[12]

IV. Spectral Resolution

The spectral resolution with 2.5-mm slits is about 0.08 μ (~2 cm^{-1} at 20 μ). With 1.5-mm slits it is





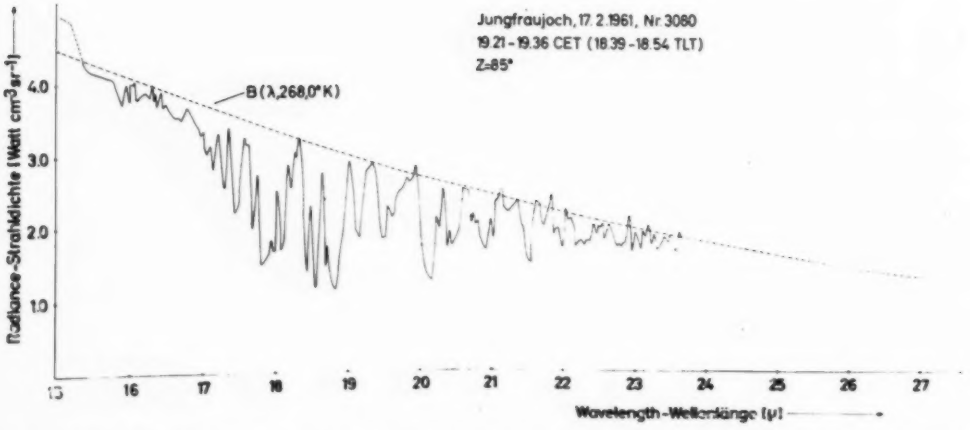
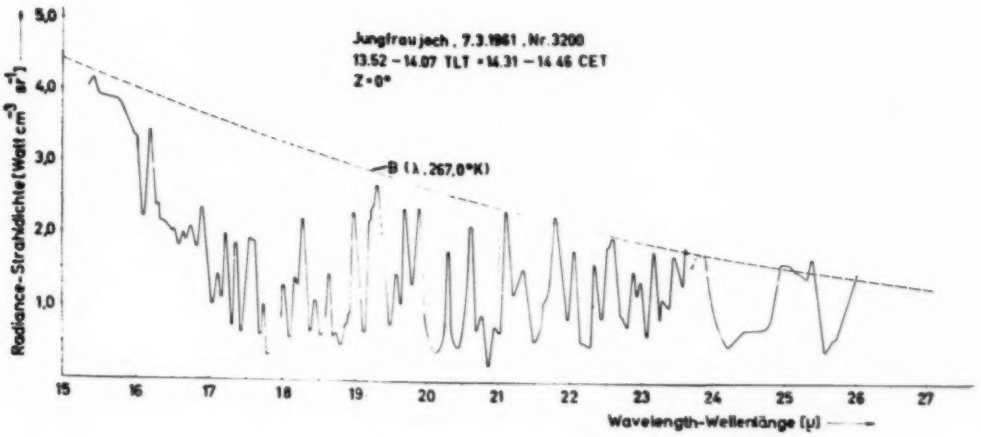
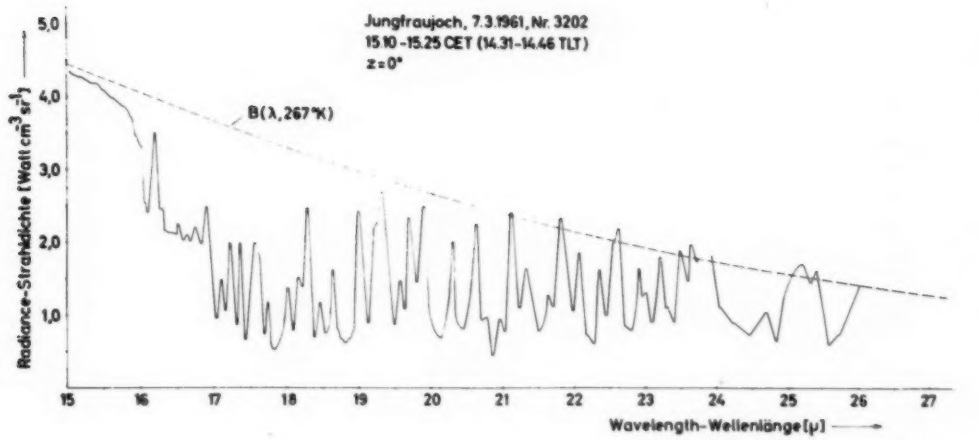
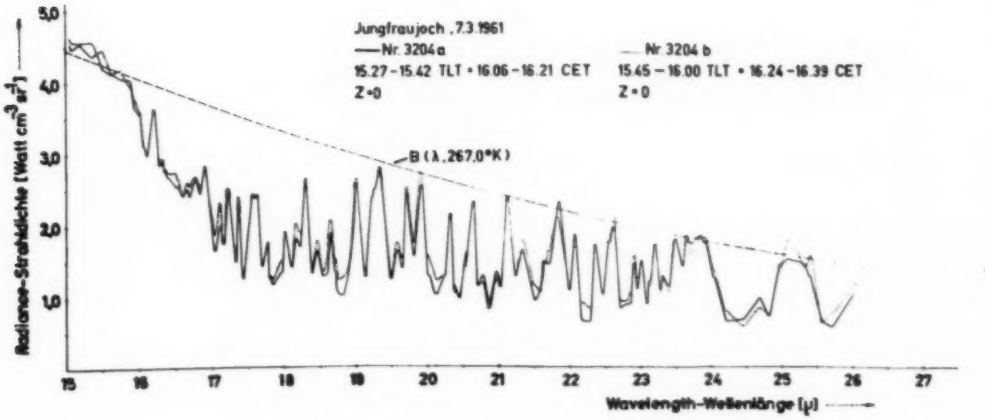


Fig. 3. Left side: Clear sky emission spectra with best obtainable resolution (1.5-mm slit width) in the 15–26 μ region, recorded on 17 February, 1961. Total amount of ppt. H_2O: ~ 0.10 cm. Ground conditions at Jungfraujoch: air temperature -5.2 to -5.5°C, pressure 666.7 mb, absolute humidity 1.06 to 0.69 g m^{-3}. Right side: Clear and cloudy sky emission spectra with 2.5-mm slit width,


Jungfraujoch, 7.3.1961, Nr. 3200
13.52 – 14.07 TLT • 14.31 – 14.46 CET
Z = 0°
B (λ, 267.0°K)
Radiance-Strahldichte [Watt cm⁻³ sr⁻¹]
Wavelength-Wellenlänge [μ]




Jungfraujoch, 7.3.1961
Nr. 3204 a
15.27 – 15.42 TLT • 16.06 – 16.21 CET
Z = 0
Nr. 3204 b
15.45 – 16.00 TLT • 16.24 – 16.39 CET
Z = 0
B (λ, 267.0°K)
Radiance-Strahldichte [Watt cm⁻³ sr⁻¹]
Wavelength-Wellenlänge [μ]

recorded on 7 March, 1961. Total amount of ppt. H_2O: 0.18 ± 0.02 cm. Ground conditions at Jungfraujoch: air temperature −6° to −6.2°C, pressure 664.8 mb, absolute humidity 0.9 to 1.1 g m^{-3}. Upper spectrum: clear sky just before clouds arrived; middle spectrum: thin cirrus stratus; lower spectrum: dense cirrus stratus (2 consecutive runs).

Table II. Window Regions Between 15 and 26 μ

Spectral region		Regions definitely located between strong line wing influence[a]		Adjacent strong lines		Remarks about windows[a]
$\lambda[\mu]$	$\nu[cm^{-1}]$	Limits $[\mu]$	$\lambda[\mu]$	Position of line center	$\lambda[\mu]$	
17.8	562.0	17.780–17.922	0.142	17.7506, 16.9420	0.1914	8 weak lines of H_2O, N_2O, CO_2, H_2O^{18}
18.4	543.5	18.384–18.447	0.063	18.3671, 18.4771		2 weak lines H_2O^{18}
18.5	540.4	18.504–18.601	0.097	18.4771, 18.6414	0.1643	2 weak lines of H_2O, CO_2
18.8	532.0	18.714–18.862	0.148	18.7119, 18.9054	0.1935	5 weak lines. Variation of continuum through window region?
19.5	512.9	19.454–19.508	0.054	19.4352, 19.5267	0.0915	2 weak lines (CO_2?)
20.1	497.5	20.020–20.204	0.184	20.0040, 20.2298	0.2258	no lines
20.5	487.8	20.472–20.580	0.108	20.4223, 20.5651	0.1428	no lines
20.8	480.9	20.833–20.895	0.062	20.8112, 20.9842	0.1730	1 weak H_2O line
21.5	465.1	21.473–21.547	0.074	21.4560, 21.5643	0.1083	no lines
22.2	450.7	22.251–22.302	0.051	22.2331, 22.3489	0.1158	no lines
22.8	438.6	22.723–22.866	0.143	22.6198, 22.9058	0.2860	3 weak lines H_2O, H_2O^{17}, H_2O^{18}
23.0	434.8	23.007–23.050	0.043	22.9922, 23.1857	0.1935	
23.2	431.0			23.1857, 23.3138	0.1281	
24.3	411.5			23.9290, 24.9580	1.0290	*X*-line 24.07 μ, *Y*-line 24.65 μ
25.6	390.5			25.3480, 25.9380	0.5900	

[a] As recognizable in the atlas of Migeotte *et al.*[2]

about 0.05 μ ($\sim$1.25 cm^{-1} at 20 μ). With this resolution it is possible to separate continuum emission from line emission in some wavelength regions. Table II lists the window regions in which this continuum could be observed.

V. Emission Spectra

Figure 3 (left part) shows some reduced emission spectra for different zenith angles as recorded with best obtainable resolution (1.5-mm slits). So far only the behavior of the continuum has been studied. The window regions, where the radiance is minimum, are listed in Table II. Absolute radiance minima occur for all recorded spectra at 17.8, 18.8, 20.1, and 20.8 μ. The 20.1-μ window seems to be most favorable for continuum investigations because no weak lines have so far been detected in this region. The spectra taken with 1.5-mm slits show a considerable amount of noise. Therefore, these narrow slits have been used on only two days. However, spectra taken with 2.5-mm slits give no serious error in the ratio of line emission to continuum emission if the "best" windows listed in Table II are used to determine the continuum, at least at not too large zenith angles. The relative mean continuum emission of the zenith as determined from 13 spectra in the window regions listed in Table II and set equal to 1.0 at 20.1 μ is plotted against wavelength at the bottom of Fig. 4. The full line (a) is a mean curve while the dashed line (b) is the minimum curve drawn through the points of the "best" windows. The variation of continuum emission with total amount of ppt. H_2O is indicated by the dotted line (c) and the upper dot-dashed line (d). These lines are "minimum" curves as is line (b), and they correspond to mean water vapor amount of 0.08 and 0.25 cm ppt. H_2O, respectively. The variation with zenith angle is shown in the upper part of Fig. 4 for a set of runs with 1.5-mm slit width. These are also "minimum" curves, drawn through the points of the best windows. The lines show irregularities which result from individual variations, but the general trend is clearly to be seen. The increase of emission at shorter wavelengths is due to the 15-μ CO_2 band. It must be mentioned that the curves in Fig. 4 do not present pure continuum emission at very large zenith angles. The empirical separation of line and continuum emission gives continuum values that are somewhat too large near the horizon.

Attempts have been made to determine the continuum absorption coefficient k_λ from the absolute sky radiance and its variation with air mass. Air mass increases as the secant of the angle from the zenith made by the line of observation. It can generally be accepted that continuum emission in this wavelength region is predominantly, if not completely, due to the wings of strong rotational water vapor lines, especially in the clear atmosphere at Jungfraujoch. So sky radiance should depend only on the temperature and humidity distribution in the atmosphere. These quantities can be determined from radiosonde measurements, which, however, have not been made at Jungfraujoch itself but in Payerne, Milano, Stuttgart, and München. Because these stations are rather far away from the measuring site, those soundings had to be selected which best matched the conditions at Jungfraujoch. To aid in this selection the surface conditions and the amount of ppt. H_2O have been recorded at Jungfraujoch. The total amount of water vapor in the atmosphere could be determined by means of an interference filter actinograph utilizing the absorption of solar radiation within the near infrared water vapor bands.[7–9] With

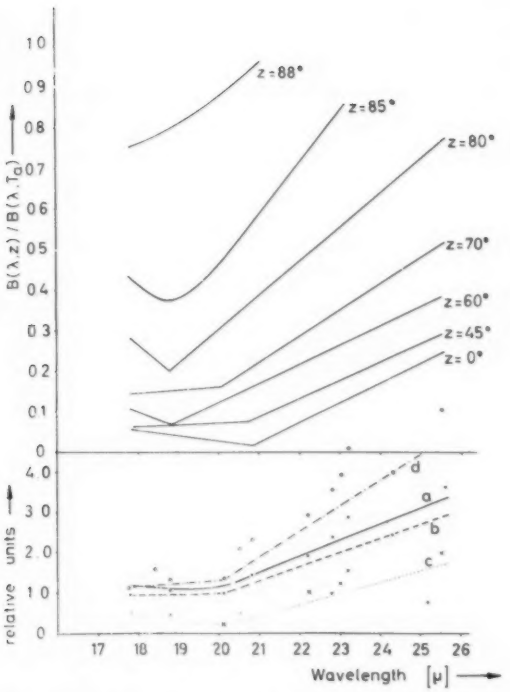


Fig. 4. Lower figure: relative values for continuum sky emission in the 16–26 μ region. ●—Mean of all zenith clear sky measurements at Jungfraujoch. The emission has been set equal to 1.0 at 20.1 μ. Amount of ppt. H_2O varying between 0.05 and 0.29 cm. ○—Mean for two clear sky zenith measurements with ~0.25 cm ppt. H_2O. x—Mean for two clear sky zenith measurements with ~0.08 cm ppt. H_2O. a—Mean curve for 13 measurements. b—Minimum of best window curve for the same 13 measurements, determined by the best windows. c—Minimum curve for 0.08 cm ppt. H_2O. d—Minimum curve for 0.25 cm ppt. H_2O. Upper figure: Variation of continuum emission with zenith angle for a set of measurements recorded on 17 February, 1961 (see Fig. 2). At zenith angles > 80° the continuum emission is influenced by line emission.

selected atmospheric soundings the radiation flux in the window regions was calculated theoretically by means of a radiation chart assuming different absorption coefficients k_λ.*

In Fig. 5 an example is given for the 20.1-μ window. The continuum radiance of five sets of measurements taken on different days is plotted against (air mass)$^{1/2}$. The slope of the curves has been smoothed out with regard to variations of individual measurements. Remaining slope differences are due to variations of sky conditions during the time of measurement (one set of measurements always took several hours.) Curves of calculated radiances are added. These curves have been derived from two selected soundings of these days with extreme amounts of ppt. H_2O. The experimental results must fall in between these limits if the absorption coefficient has the correct value. So, if the absorption coefficient is varied, the theoretical limits can be fitted to the measurements. However, the k_λ-values derived in this way are still preliminary values. In a more detailed discussion each set of measurements have to be compared with calculated data derived from soundings which exactly match the meteorological conditions at the time of measurement. The absorption coefficients have first been determined without any correction applied to the radiosonde data. The k_λ-values determined in this way are valid only for the conditions on the Jungfraujoch. This has been indicated by an asterisk. Then k_λ-values have been calculated with pressure-reduced water vapor values, using the reduction $p/1000$ mb. Of course, this reduction is not completely valid as can be seen from the data derived from Palmer's laboratory measurements[12] which are added in Table III, but the reduction has been applied because it is the maximum reduction which has been taken into consideration by other authors (a $\sqrt{p/p_0}$ reduction also gives incorrect values if applied to the data of Palmer). Absorption coefficients which have been determined in this way are listed in Table III. Of course these k_λ values do not correspond to the generalized absorption coefficients of this region derived by Elsasser[13], Möller,[14] or Yamamoto[15] because these are mean values for line and window absorption together. Also the absorption coefficients derived by Weber and

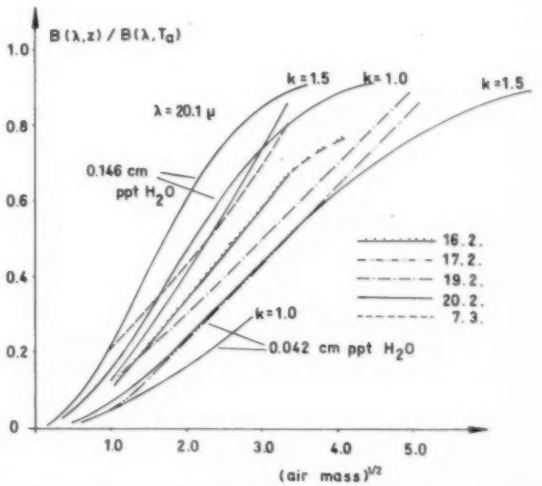


Fig. 5. Ratio of continuum emission to air temperature blackbody emission at 20.1 μ for five sets of measurements plotted versus (air mass)$^{1/2}$. For comparison theoretical values are added, which have been calculated by means of a radiation diagram from two radiosonde ascents of these days with extreme amounts of ppt. H_2O (0.146 resp. 0.042 cm) using an absorption coefficient of k_λ = 1.0 and 1.5, respectively (without pressure reduction).

* This procedure will be discussed in detail in a paper of Bolle, Quenzel, and Zdunkowski to be given at the Meeting on Alpine Meteorology, Sauze d'Oulx-Sestrière, Italy, and will be published in *Geofis. pura e appl.*

Table III. Preliminary Absorption Coefficients for 17–25 μ Continuum

Window region [μ]	k^*_λ[a]	$k_{\lambda,r} \cong 1.7\, k^*_\lambda$[b]	$k_{\lambda,P}$[c] 815 mb	272 mb	mean (~550 mb)	$k_{\lambda,TY}$[d]	$k_{\lambda,TY}/k_{\lambda,r}$
17.8	0.85	1.45	—	—	—	2.12	1.5
18.8	1.0	1.7	—	—	—	2.89	1.7
20.1	1.25	2.1	—	—	—	2.35	1.1
22.8	3.5	6.0	—	—	—	8.41	1.4
24.3	3.2	5.4	5.4	3.2	4.3	—	—
25.6	6.0	10.0	10.5	4.8	7.7	—	—

[a] k^*_λ is the absorption coefficient for Jungfraujoch determined without any correction (ground pressure ~665 mb).
[b] $k_{\lambda,r}$ is the reduced absorption coefficient determined with pressure correction $p/1000$ mb on water vapor mass.
[c] $k_{\lambda,P}$ is the absorption coefficients derived from spectra of Palmer[12]; water vapor pressurized with nitrogen, 0.074 resp. 0.143 cm H_2O in optical path. The pressure of 550 mb corresponds to an atmospheric level of about 1600 m above Jungfraujoch.
[d] $k_{\lambda,TY}$ is the absorption coefficient determined from one transmission spectrum of Taylor and Yates.[17]

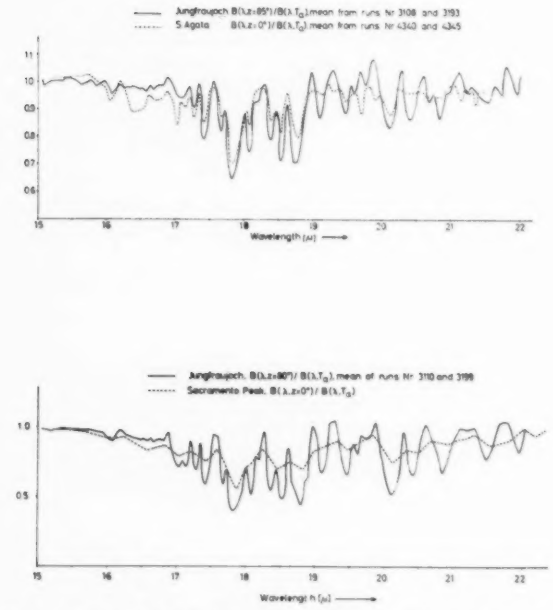

Jungfraujoch B(λ,z=85°)/B(λ,T0) mean from runs Nr 3108 and 3193
S.Agata B(λ,z=0°)/B(λ,T0) mean from runs Nr 4340 and 4345
Wavelength (μ)
Jungfraujoch. B(λ,z=80°)/ B(λ,T0) mean of runs Nr 3110 and 3199
Sacramento Peak. B(λ,z=0°)/ B(λ,T0)
Wavelength (μ)

Fig. 6. Ratio of sky emission at zenith angle z to air temperature blackbody radiance for different spectra (see Table IV).

Randall[16] are still larger in the window regions. Absorption coefficients calculated from one record of a transmission experiment carried out by Taylor and Yates[17] and laboratory measurements of Palmer[12] on nitrogen–water vapor mixtures are additionally listed in Table III. They too give somewhat higher values than have been obtained here. However, the actual atmospheric absorption coefficients should be smaller than values derived from nitrogen pressurized experiments because the quadrupole moment of oxygen is only one third of the nitrogen moment.[18]

In the majority of the 15–26 μ interval, water vapor is the predominant emitter in the atmosphere. If only the optical path length influences the emission and if the pressure reduction is uniform through the spectrum, Jungfraujoch spectra should be directly comparable with zenith spectra taken at other stations, for similar water vapor masses. In Fig. 6. such a comparison has been made between spectra recorded at Jungfraujoch and at S. Agata (near Sorrento), Italy, and also with a spectrum recorded by Burch and Shaw[19] at Sacramento Peak. The ratio of sky radiance to the radiance of a blackbody at air temperature on ground has been plotted against wavelength. In general Jungfraujoch spectra

Table IV. Meteorological Parameters for the Spectra of Fig. 6

Run no.	Place	z [°]	Relative water vapor mass	Date	Ground conditions: Temp. [°K]	Press. [mb]	Abs. hum. [g m^{-3}]	ppt. H_2O [cm]	Mean ppt. H_2O × water vapor mass
3110	Jungfraujoch	80	5.7	20.2.61	265.8	660.5	1.0	0.23	1.05
3199	Jungfraujoch	80	5.7	7.3.61	267.2	664.8	1.3	0.14	
3108	Jungfraujoch	85	11.1	20.2.61	266.0	661.2	1.1	0.33	2.6
3193	Jungfraujoch	85	11.1	7.3.61	267.0	666.5	1.3	0.14	
4340	S. Agata	0	1	4.9.61	297.5	967.5	13.3	1.6	1.6
4345	S. Agata	0	1	5.9.61	294.0	967.0	7.0	1.3	1.3
Bu.S	Sacramento Peak	0	1	30.9.55	287.0	—[a]	4	—[a]	—

[a] By comparison with the Jungfraujoch spectra an amount of ~1 cm ppt. H_2O follows.

taken at zenith angles of 80° and 85° correspond to Sacramento Peak and S. Agata zenith spectra, respectively. Meteorological data are listed in Table IV.

From both examples it can be seen that the ratio of the Jungfraujoch sky emissivity to the zenith emissivity under more humid conditions decreases in the mean with wavelength.

In the 20–22 μ region the zenith radiation at S. Agata and Sacramento Peak is "blacker" than the sky at Jungfraujoch at 5° and 10° above the horizon, respectively. The effect is of course smaller for Sacramento Peak than for S. Agata. The line structure in this wavelength interval is more pronounced in the Jungfraujoch spectra than in the other spectra. This is opposite to that observed in the 16–17 μ region and indicates that the emissivity at Jungfraujoch decreases with wavelength relative to the emissivities measured at the other stations. However, such a variation with wavelength is not apparent from a comparison of the continuum absorption coefficients for Jungfraujoch with the measurement of Taylor and Yates (Table III, last column). On the contrary, the continuum absorption coefficient derived from the Jungfraujoch emission studies has its smallest values at the two short wavelengths compared with the Taylor and Yates values. Therefore, the different wavelength dependence of the emissivity at Jungfraujoch and S. Agata cannot be interpreted in terms of temperature or pressure effects. It is much more likely that the effect is due to the influence of the 15-μ CO_2 band on the shorter wavelengths up to about 18 μ. It requires a slant path with a very large zenith angle at the Jungfraujoch to contain the same amount of water vapor that is present in a vertical column of the atmosphere bounded by the ground at sea level and by the top of the atmosphere. On the other hand, the carbon dioxide mass of this slant path exceeds by far the amount of carbon dioxide in the vertical path above sea level. With respect to the water vapor emission it would therefore be more suitable to compare the S. Agata zenith spectrum with a Jungfraujoch spectrum recorded under a zenith angle still larger than 85°.

The spectra have to be adjusted at wavelengths larger than 18 μ. As can be seen from Table IV the water vapor mass in the optical path at Jungfraujoch would in this case greatly exceed the zenith amount of ppt. H_2O at S. Agata. From the differences of ppt. H_2O in the two optical paths and from soundings of the atmosphere in both places conclusions could be drawn with regard to the pressure reduction, if more measurements of this type were available which were made under different climatic conditions. In order to be comparable with respect to carbon dioxide emission, the S. Agata zenith spectrum would correspond to a Jungfraujoch spectrum of about two air masses, in the wavelength region between 15 and 18 μ.

VI. Emission of Cirrus Clouds

On March 7, 1961, a uniform cirrus cloud cover drifted in from the north over the Jungfraujoch station. At first, the clouds were thin and still transparent enough that the blue sky could be seen. The cloud cover gradually became more dense until it was uniformly white, with no evidence of blue sky. The four spectra on the right-hand side of Fig. 3 were taken on this day, one before there was any cloud cover, the second with the thin stratus cloud cover, the third and fourth with the dense cirrus cloud cover at the zenith. The two consecutive emission measurements with the dense cirrus stratus in the zenith gave almost no variations, the clouds being at that time very uniform.

The transmissivity of the clouds to solar radiation as measured with the interference filter actinograph was 15–30% at about air mass three. The value of 15% seems to correspond to the dense cover of which the emission has been studied, while 30% corresponds to less dense regions of the clouds, which were not as uniformly dense beyond the zenith. If 85% is accepted for the extinction in the dense clouds at three air masses, then its value would be about 50% at one air mass.

In Fig. 7, a plot of the difference of the sky emission with clouds from that without clouds against wavelength is given. The sky emission without clouds is taken from the observed emission in the windows (as given in Table II). In obtaining this difference, the absorption between the cloud layer and the observation point is neglected. The observed differences are indicated by points. The lower curve represents the emission of the clear sky, while the points on this graph are the emission obtained from the spectrum observed with thin clouds. These thin and translucent clouds had only a very small influence on the clear sky emission. The influence of the dense cloud layer was marked but was smaller than expected. In the case of the dense clouds the points have been corrected for the absorption between cloud cover and ground by means of the absorption coefficient derived from the emission spectra (Table III) and the known amount of ppt. H_2O in the atmosphere up to about 10 km height. The corrected cloud emission is drawn as full line above the points. Above this spectral emission of the cloud layer there are given blackbody curves for 212°K and 220°K. These are the temperatures of the 10.8-km and 9.8-km levels, respectively, as determined from the radiosonde ascent of Stuttgart on that day. If a temperature of 212°K is accepted, the cloud emissivity is about 0.65 at 17.8 μ and drops to 0.29 and 24.3 μ. The mean value is in fairly good agreement with the extinction measurement at 1.6 μ, made with the interference filter actinograph. A possible explanation of the decrease in cloud emissivity toward longer wavelengths is to assume that there are ice droplets formed in the clouds. There is a small decrease in the absorption coefficient of ice[20] be-

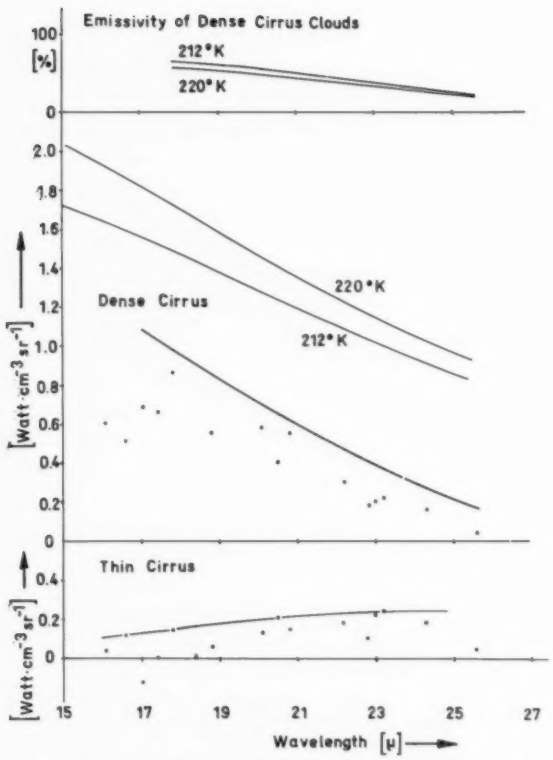


Fig. 7. Emission of cirrus clouds (compare Fig. 2, right side). Lower figure. Points—Difference of zenith emission with thin cirrus clouds and clear sky shortly before. Curve—Maximum cloud emission (not corrected for absorption between clouds and ground). Middle figure. Points—Difference of zenith emission with dense clouds and clear sky. Curve—Cloud emission corrected for absorption between clouds and ground. Above blackbody emission for 212 and 220°K, the assumed cloud temperatures. Upper figure. Emissivity of dense cirrus clouds assuming cloud temperatures of 212 and 220°K, respectively.

tween 15 and 25μ. Shifrin[21] computed that the absorption coefficient for water clouds drops rapidly as the radius of the droplets decreases such that $1 < 2\pi a/\lambda \rightarrow 0$, where a is the radius of the droplets. The same effect might hold for ice clouds, though the absorption coefficient and its wavelength dependence are different for ice and water. At 20 μ, the quantity $2\pi a/\lambda$ is smaller than 1 only if the particle radii are smaller than 3 μ. The magnitude of this effect is not sufficient to account for the entire observed difference, however.

That the dense clouds decrease in emissivity with wavelength while the thin clouds increase cannot be explained satisfactorily. One possibility is that the emission at the shorter wavelengths is mainly influenced by the droplets or particles while at longer wavelengths it is mainly a function of the concentration of water vapor in the cloud layer. This does not increase very much even when clouds appear.

The small increase of emission with wavelength for the thin clouds is not an effect of the cloud density increasing during the measurements. The spectrum was actually recorded starting with the long wavelength end and proceeding toward shorter wavelengths.

The writer is especially grateful to F. Möller for many stimulating discussions on this work. It is a pleasure to thank W. Zdunkowski for the preparation of the radiation diagram and H. Quenzel for the interference filter actinograph measurements. Furthermore, the author acknowledges gratefully the assistance of B. Pornitz, G. Dreyer, and a number of students, who made the extensive numerical evaluations. The work could not have been carried out without the generous sponsorship of the Air Force Cambridge Research Laboratories, through the European Office of Aerospace Research. We are particularly indebted to this agency.

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Absorption by Ozone in the 4.75-Micron Region of the Solar Spectrum

D. J. McCaa and J. H. Shaw

Solar spectra in the region of the 4.75-μ ozone band have been obtained on a new high-resolution grating spectrometer. By comparing the solar spectrum with a laboratory spectrum of this O_3 band, almost 300 O_3 lines have been identified in the solar spectrum. This region of the solar spectrum also contains lines of H_2O, CO, and CO_2, which greatly perturb the appearance of the O_3 band in the solar spectrum.

Ozone is a minor constituent of the earth's atmosphere, but its absorption bands in the ultraviolet and infrared have significant meteorological effects. In addition to the far-infrared pure-rotation band of O_3, vibration-rotation bands occur at 14, 9.6, 9.0, and 4.75 μ. Other weaker bands lie at shorter wavelengths. All of these bands consist of many closely spaced lines with an average spacing of less than 0.2 cm^{-1}. Since it has not been possible to obtain this resolution in the 5-μ region of the spectrum, most of the structure of the 4.75-μ band has not been observed. Recently, spectra of the 4.75-μ band of O_3 have been obtained in this laboratory with an instrument capable of resolving lines closer than 0.06 cm^{-1}. Over 300 lines of this band have been observed, and many have been identified in solar spectra of the same region taken with the same instrument.

The Spectrometer

The Ebert-type grating spectrometer with which these studies were made was designed by D. E. Burch; a schematic diagram of the optical path is shown in Fig. 1. The source tank contains a Nernst glower and space for a sample cell. There is also a window in this tank to allow radiation from other sources, e.g., the sun, to enter the spectrometer. When solar spectra are being recorded, the solar radiation from a coelostat on the roof of the laboratory falls on a spherical mirror which forms an image of the sun 4 or 5 cm in front of this window. The main tank contains the foreprism and grating optics, and different detectors can be mounted at each end of the detector tank. All three tanks can be evacuated independently.

Radiation from the source falls on the entrance slit of the foreprism section and is dispersed by a CaF_2 foreprism. The frequency of the radiation falling on the entrance slit of the grating section is varied by rotating the Littrow mirror behind the foreprism. After passing through the curved entrance slit (radius of curvature = 15.24 cm) of the grating section, the radiation is collimated by a 53.0-cm diam spherical mirror (radius of curvature = 457.0 cm) and reflected to the grating. Part of the diffracted beam is returned to the spherical mirror, and radiation that is symmetric with respect to the entrance slit passes through the exit slit of the grating section. The exit slit is at the primary focus of an elliptical mirror, and the detector is placed at the secondary focus, giving a 10:1 reduction in the size of the final image on the detector.

A Bausch & Lomb replica of a 25.4-cm × 12.7-cm grating ruled by Harrison with a blaze angle of 48° and 300 lines/mm was used in this study. The grating is mounted on a spindle bearing and moved by a sine-bar drive which is driven by a precision screw and gives very good reproducibility.

The radiation is chopped at 450 cps by a mechanical chopper located at the entrance slit of the foreprism section and detected by a liquid nitrogen-cooled PbSe cell manufactured by the Santa Barbara Research Center. The signal is amplified by a Baird-Atomic 450-cycle amplifier and phase-sensitive detector and recorded on a Leeds and Northrup strip-chart recorder.

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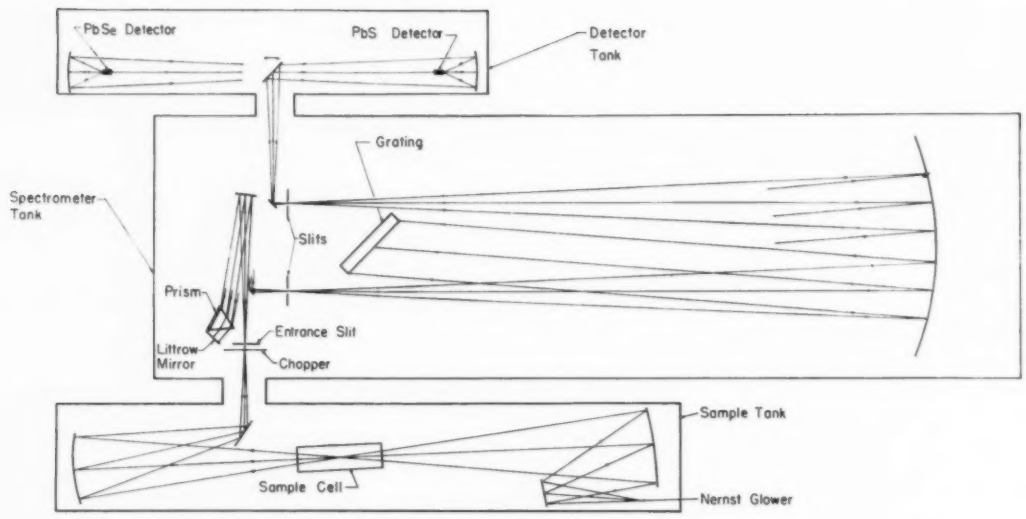

Fig. 1. Optical diagram of the Ebert spectrometer.

Experimental Results

A portion of the solar spectrum from 2050 to 2150 cm^{-1}, recorded between 9 and 10:30 a.m. on August 11, 1962, when Columbus was in the center of a cold, relatively dry air mass, is shown in Figs. 2 and 3.

This portion of the solar spectrum contains absorption lines of CO, CO_2, H_2O, and O_3, many of which have been identified in previous studies.[1-5] Many of the lines of H_2O are sufficiently intense to absorb completely all the solar radiation at their centers in the solar spectrum observed at Columbus.[2,6] These lines have not been labeled in the figures.

Carbon Monoxide

The rotational lines from $R(0)$ to $P(22)$ of the 1-0 fundamental band of telluric $C^{12}O^{16}$ are prominent in this region of the solar spectrum. These lines have been labeled at the top of each row. Weaker lines of the 1-0 bands of isotopic CO molecules in the earth's atmosphere are also present. In addition, CO in the solar atmosphere gives absorption lines in this region. Because of the high temperature of the solar atmosphere, lines of the 2-1, 3-2, 4-3, and 5-4 hot bands of CO can be observed, and some of these have been identified previously.[1,5] Lines of the 2-1, 3-2, and 4-3

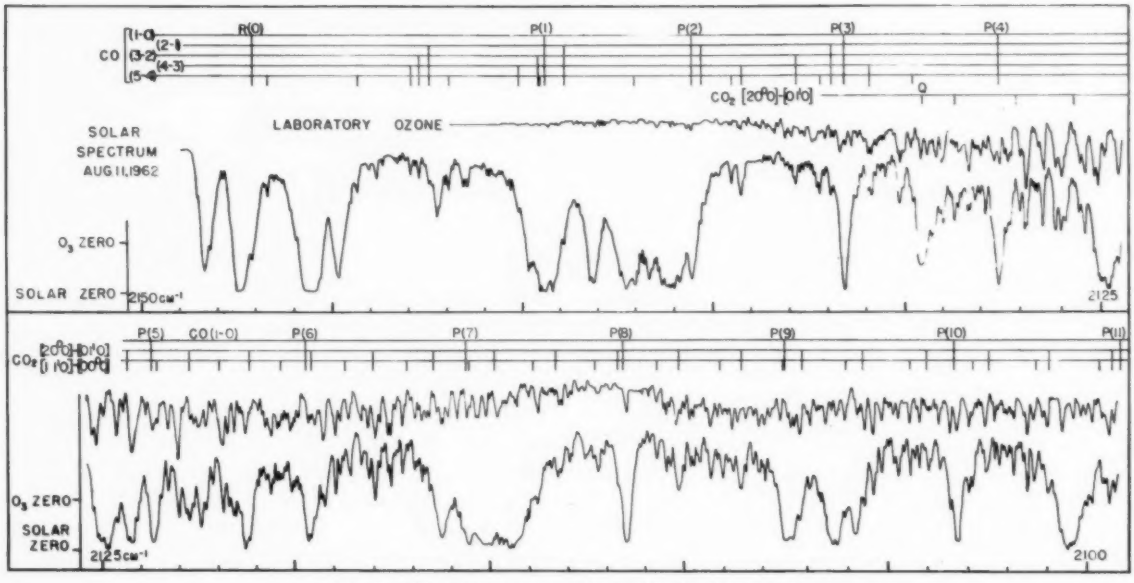

Fig. 2. The solar spectrum from 2100 to 2150 cm^{-1}.

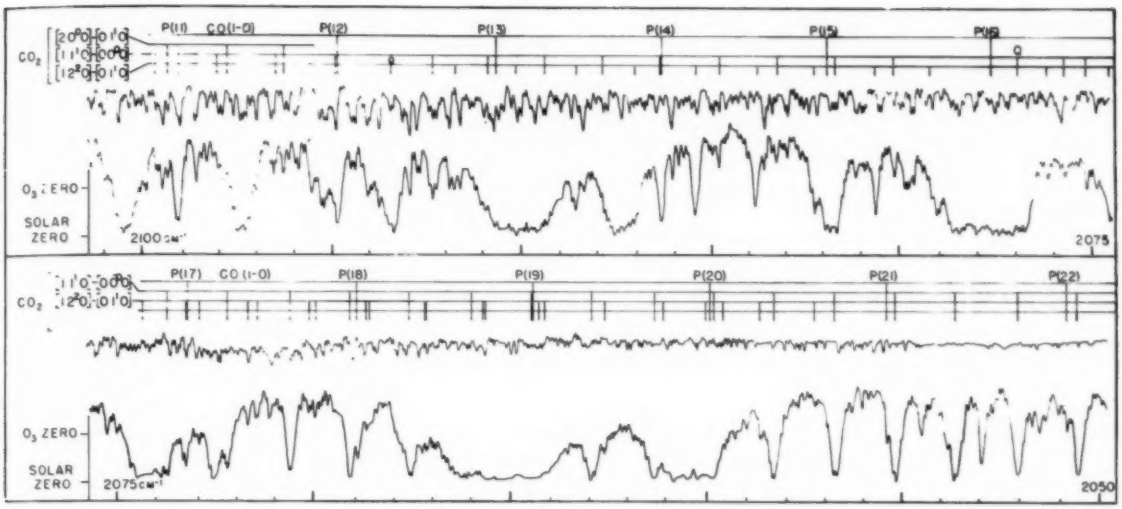

Fig. 3. The solar spectrum from 2050 to 2100 cm^{-1}.

hot bands of CO have recently been measured in the laboratory by Birkeland,[7] and these data have been used to confirm the identifications. Some additional hot-band lines have been resolved in the present spectra; however, these lines are hidden, at longer wavelengths, by O_3 absorption. Beyond the O_3 band, many more weak lines have been observed in addition to those previously noted by Migeotte et al.[5] Many of these are probably due to solar CO, although they have not yet been identified.

Carbon Dioxide

Three *Q*-branches, three *P*-branches, and one *R*-branch due to CO_2 have previously been identified in this region of the solar spectrum.[5] The three perpendicular bands giving rise to these lines have been observed in the laboratory by Barker and Wu,[8] and the *Q*-branches at 2077.1, 2093.4, and 2131.5 cm^{-1} are labeled in Figs. 2 and 3. In the present study, a laboratory spectrum of CO_2 was obtained by filling the main and detector tanks of the spectrometer with CO_2 to a pressure of 14 cm of Hg, to give a total path length of 12 m. In this laboratory spectrum many of the calculated line positions given by Migeotte *et al.*[5] have been confirmed. In the region of the solar spectrum between 2055 and 2075 cm^{-1}, weak lines of the *P*-branch of $[12^20]$-$[01^10]$ can be seen, but many of the weaker lines of this and the other 2 bands are hidden by O_3 absorption at shorter wavelengths.

Ozone

The laboratory O_3 spectrum shown above the solar spectrum in Figs. 2 and 3 was taken with a pressure of 4.0 cm of Hg of O_3 in a 30-cm cell. The O_3 was prepared by passing dry O_2 through a silent gas discharge. The resulting O_2 and O_3 mixture was then passed through a liquid N_2 trap where the O_3 was liquefied together with a small amount of O_2. The O_2 was removed by pumping, and the remaining O_3 was allowed to evaporate slowly into the sample cell. As can be seen in Figs. 2 and 3, much of the fine structure in the solar spectrum in the region from 2050 to 2150 cm^{-1} is due to O_3, and a total of 292 O_3 lines have been identified in the solar spectrum.

Migeotte *et al.*[4,5] have previously observed some of these O_3 lines both in laboratory spectra and in solar spectra obtained at the Jungfraujoch Observatory. They have given 80 O_3 line frequencies in the region from 2056 to 2131 cm^{-1}. Many additional lines have been observed in the present solar spectrum, most of which are primarily due to O_3. However, the list of identifications given in ref. 5 indicates the complexity of this region of the solar spectrum. In addition to the perturbations introduced by H_2O and CO lines, there are many weak CO_2 lines that cause apparent intensity anomalies in the O_3 band as observed in the solar spectrum. The present laboratory spectrum indicates that the O_3 band extends from 2060 to 2135 cm^{-1}, with its band center at 2111 cm^{-1}.

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Applied Optics BOOKS

Books for review should be submitted to the Managing Editor, APPLIED OPTICS, 1155 16th St., N.W., Washington 6, D.C.

Instrumental Optics. By G. A. Boutry; translated by R. Auerbach. Interscience Div. of Wiley, New York, 1962. 544 pp. $27.50.

Professor Boutry, through the very able translation by Mr. Auerbach, has produced a volume of considerable interest. This reviewer found it a great pleasure to read in detail many sections of this book and to scan others. The science of optics in a sense reached a technical plateau during the war years and through the remainder of the decade preceding 1950. This treatise is a fine monument to the preceding period of development. Partially due to the fact that the author was in a very real sense isolated from many of the military developments and applications of optical instruments, partially due perhaps to his personal interests, the instruments to which he refers are the classical microscope, telescope, magnifiers, photographic objectives, and, at the very end, some spectroscopes and spectrographs among others. Although phase contrast in microscopy and the Schmidt telescope are both referred to, the great steps forward in large telescope-type instruments, brought on by the space era, the complex periscopes of the atomic age, the very high performance photographic objectives, all have come after the original writing of this book and are not discussed.

The section on the microscope is unusually good, whereas the section on the telescope is quite disappointing in its brevity. On the other hand, there are occasional indications that the great revolution to come, brought about by electronic computing machinery, the need for very high-resolution diffraction limited systems, the special problem of very high-precision optics, and the whole concept of the modern methods of image evaluation were glimpsed by Boutry, even though none of these specific subjects is dealt with directly. Compared with the normal textbooks on the fundamentals of optics commonly used in this country, Boutry treats each point in much more detail, and this reviewer found the discussions much more difficult to follow. On the other hand, when compared with such treatises as Conrady or Linfoot in the area of optical design, *Instrumental Optics* of necessity is much less complete. It is unusual to find a treatment of complex relations in which so much space is devoted to descriptive material interspersed between the various mathematical relations. However, there is great pleasure awaiting the reader as he discovers the occasional new concept or an old friend presented in a novel and interesting fashion. The illustrations are unusually well done, particularly those which treat the problems of concepts in three dimensions.

No review would be complete without a specific mention of the excellent work performed by the translator. Although some of the flavor of the French approach is retained and the interest increased thereby, the language is not a barrier to the understanding of the thought, and on many occasions the word selection and sentence structure give a feeling of pleasure to the reader. This is a fine example of a technical treatise presented in readable and interesting English. In essence then, this volume undoubtedly can take its well-earned place as a milestone in the history of optics rather than find itself widely used either as a textbook or work of reference.

R. M. Scott

Technical Glasses. By M. B. Volf. English Translation by Sylvia E. Myhre and K. Fink. SNTL, Publishers of Technical Literature, Prague, and Sir Isaac Pitman and Sons Ltd., London. 465 pages. $10.00.

The great majority of the glasses discussed in this book are European glasses for technical uses. The author points out in the preface that "special glasses related to optics" are not discussed. This limits the book to "technical glasses" which are defined as "glasses generally used in laboratory equipment, industrial production plant, electronics and health services." The properties of commercially available glasses made in Czechoslovakia, France, East Germany, West Germany, England, Holland, Poland, the Soviet Union, and the United States are given. The American glasses listed are those given in the catalogs of Corning Glass Works and Kimble Division of Owens-Illinois.

The first two chapters are devoted to the theory of the glassy state and to a discussion of the physical properties of glass and the methods used to measure them. As for theoretical considerations the author reviews the various theories and then summarizes by saying: "Neither the Zachariasen-Warren theory of the network structure of glass assuming a continuous statistical disorder of structural units, nor Lebedev's theory of crystallites presenting glass as 'an agglomeration of micro-crystalline formations which may represent either some definite chemical compounds, or solid solutions, and which must be in accordance with the diagram of the respective system' hold in every respect. The majority of technical glasses lies between both of the extreme cases."

Among the properties discussed in the second chapter are the following: thermal expansion, thermal endurance (Δt that the glass article will endure without breaking), chemical durability (5 hydrolitic classes), density, specific heat, thermal conductivity, mechanical properties, electrical properties, viscosity, and annealing. Some of the tests described are those peculiar to Europe and may not be familar to most American readers. An example is the DGG (Deutsche Glastechnische Gesellschaft) method for the determination of chemical durability. However, certain ASTM tests are given along with their European counterparts, as well as tests designated by the International Organization for Standardization (ISO).

Following the two introductory chapters, glasses are classified according to their various uses and are discussed in separate chapters. Some of the chapter headings are Sial Glasses, Pyrex Type Glasses, Simax Glass, Vycor, Instrument Glasses, The Glass Electrode, Sealing Glasses, Glasses for Discharge Lamps, Hard Glasses, Fibreglass, etc. Within each chapter glasses are listed by composition and the author states that more than 850 compositions are listed.

The index was not found to be adequate in all cases. For instance, the well-known "Thuringian glasses" are discussed in the chapter on Instrument Glasses but the term is not listed in the index. For the most part the translation into English is excellent. A few terms are found whose meaning is not clear, i.e., "colourless glass crystals," p. 36. In some places in the text commas appear to be used as decimal points, following the European custom. Evidently, these slipped through in the proofreading.

Since glasses have such a wide variety of applications in science and technology this book should be of considerable interest to those concerned with the compositions and properties of glasses, particularly European glasses. The book is unique in that it gives the compositions of so many commercial glasses. Many of the compositions are scattered through the literature but they are certainly not to be found elsewhere under one cover.

Given W. Cleek

Books *continued on page 589*

Total Absorptance of Water Vapor in the Near Infrared

Darrell E. Burch, Wilbur L. France, and Dudley Williams

The total absorptance $\int A(\nu)d\nu$ of water vapor in the vicinity of its vibration-rotation bands near 5332, 3700, and 1595 cm^{-1} has been determined as a function of absorber concentration w and equivalent pressure P_e for pure water vapor samples and samples of water vapor mixed with nitrogen. The present results, together with previously published results of Howard, Burch, and Williams, are presented in graphical form; logarithmic plots give $\int A(\nu)d\nu$ for various values of P_e as a function of absorber concentration w. These plots may be used in estimating total absorptance of water vapor in any sample for which w and P_e are known, and they may be applied in atmospheric studies.

The present paper is the fourth in a series of papers[1-3] dealing with the total infrared absorptance $\int A(\nu)d\nu$ of atmospheric gases as a function of absorber concentration w and equivalent pressure P_e. The general experimental methods and the symbols and nomenclature employed were introduced in the first paper in the series and in a still earlier paper on line broadening in the infrared.[4] The study of water vapor described in the present paper was undertaken with a view to supplementing the previous work of Howard, Burch, and Williams[5] (HBW) and a still earlier investigation by Chapman and Howard.[6] The present work represents an advance over the previous studies of water vapor in view of (i) the use of improved optical and electronic equipment to give higher signal-to-noise ratios and higher spectral resolution, (ii) a more reliable method of determining absorber concentrations, and (iii) the use of an improved method of taking account of the self-broadening effects of water vapor.[4]

Experimental Methods

The major vibration-rotation bands of water vapor in the near infrared are the combination band $\nu_2 + \nu_3$ at 5332 cm^{-1}, the ν_3 and ν_1 fundamentals near 3700 cm^{-1}, and the ν_2 fundamental at 1595 cm^{-1}. Although the centers of the ν_3 and ν_1 bands occur, respectively, at 3756 cm^{-1} and 3652 cm^{-1}, for the purposes of the present study these two overlapping bands are called *the* 3700 cm^{-1} band; absorptance of the much weaker band $2\nu_2$ at 3151 cm^{-1} was measured but is not included in the present analysis of total absorptance.

The major bands were studied by means of a Perkin-Elmer Model 99 spectrometer mounted in a vacuum tank to eliminate spurious effects due to atmospheric water vapor and carbon dioxide; a LiF prism was used for the 5332 and 3700 cm^{-1} bands and a NaCl prism for the 1595 cm^{-1} band. A Reeder thermocouple was employed as a detector for all bands. The use of a multiple-traversal cell designed to fill the spectrometer optics provided absorption path lengths of 6 to 48 meters; this range of path lengths is approximately the same as that used by Chapman and Howard but is considerably less than the range 88 to 1408 meters covered in the HBW work by means of a 22-meter multiple-traversal cell that was improperly matched to the spectrometer optics. The temperature of the cell used in the present work was carefully monitored; possible spurious effects due to slow temperature drifts were minimized.

Since water vapor is condensable, it is inappropriate to express absorber concentrations in atm cm at STP as in the case of the gases treated in the earlier papers in the present series. Water vapor concentrations w will be expressed in precipitable centimeters (pr. cm), which gives the thickness of the layer of liquid water that would be formed if all water vapor in the absorption path were condensed in a vessel having the same cross-sectional area as the cell. Values of w in pr. cm are numerically the same as if they were expressed in g/cm^2. The relatively low saturated vapor pressures

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of water at ambient temperatures together with uncertainties due to adsorption on the cell walls have presented formidable difficulties to the accurate determination of absorber concentrations in earlier studies; the influence of cell temperature variations and the influence of the addition of nitrogen or other line broadening gases have introduced additional uncertainties.

When water vapor alone is in an absorption cell, it is possible to determine absorber concentration with some certainty by measuring the pressure of the water vapor, since the absorber concentration is directly proportional to the product of vapor pressure p and absorption path length l. In the absence of adsorption, it would also be possible to calculate absorber concentration by allowing a known quantity of liquid water to evaporate into a previously well-evacuated absorption cell of known volume, being careful to avoid condensation; the vapor pressure p can be calculated on the assumption that all the added water remains in the vapor phase with no adsorption. Experiments in the present study showed that at ambient temperature the initial values of p as measured with a manometer were 40 to 60% as great as the values calculated on the basis of no adsorption; this result indicates that approximately one-half the water added was immediately adsorbed on the steel walls of the cell. If the sample was left in the cell at constant temperature, the pressure as measured by the manometer was found to decrease gradually for several hours, a result showing that further adsorption occurred slowly before a final equilibrium value of p was attained. If the cell temperature was then increased, it was found that the measured values of p increased by an amount considerably greater than that to be expected on the basis of the gas laws; a considerable portion of the observed increase must therefore be attributed to the desorption of water vapor accompanying temperature increase.

Various coatings such as lacquer, glyptal varnish, and a thin layer of vacuum pump oil were applied to the interior walls of the cell to reduce adsorption. None of these coatings seemed to change the effects of adsorption by a significant amount; however, more time was required for the pressure to attain equilibrium and to "degas" the cell walls by evacuation when these coatings were used. Therefore, the cell was used with the bare steel exposed; little differences in adsorption were observed for cell walls of freshly sand-blasted steel and cell walls coated with a thin layer of "rust." It is possible that a porcelain or glass coating might have been desirable but would have involved considerable expense not justified in view of the fact that a satisfactory method of monitoring water vapor pressure was eventually developed.

As indicated above, no serious problems in the determination of w are encountered with pure samples of water vapor in the absorption cell since vapor pressure can be monitored directly and continuously with a manometer. However, when nitrogen is added, the water vapor pressure can no longer be measured directly. In the HBW work, it was *assumed* that, once an "equilibrium pressure" had been attained with water vapor alone in the cell, the addition of nitrogen would not disturb the equilibrium between adsorbed water and water vapor; in other words, that the nitrogen even at high pressures would neither displace adsorbed water nor cause additional water to be adsorbed. The validity of this assumption has been questioned, and there has been some speculation regarding the validity of certain of the HBW results for water vapor.

In the present study the partial pressure of water vapor, from which w can be calculated, was determined by measuring the *dew point* of the sample in the absorption cell. This was accomplished by means of a "well" consisting of a piece of Inconel tubing with its lower end closed and with its upper end soldered to a hole in the absorption cell wall. The Inconel well projected approximately 20 cm into the interior of the absorption cell. Ether was placed in the well and nitrogen was bubbled through until evaporative cooling reduced the well temperature to the point at which the onset of condensation on the external surface of the well occurred; condensation was observed through a small window in the wall of the absorption cell. A thermometer immersed in the ether was used to determine the temperature at which condensation began.

Turbulence in the ether produced by the nitrogen bubbles minimized temperature gradients in the ether; thermometer readings varied by not more than ± 0.1 to 0.2°C at various points in the ether. With slow cooling there was probably little difference in temperature between the Inconel condensation surface and the ether. However, the usual difficulties were encountered in selecting proper criteria for the onset of true condensation; a light, fairly stable film appeared on the polished surface at a temperature 0.2°C above that at which continued condensation occurred. Experiments with water vapor alone in the absorption cell indicated that the lower temperature corresponded more closely to the true dew point; comparison of vapor pressures given by dew point measurements with vapor pressures measured by means of a manometer showed agreement to $\pm 2\%$ for relatively high values of the dew point. It is believed that values of w based on dew point measurements in the present study are valid to $\pm 2\%$ to $\pm 3\%$ for samples with dew points higher than 10°C and to $\pm 3\%$ to $\pm 4\%$ for samples having lower dew points.

In preparing samples consisting of water vapor and nitrogen, water vapor was first introduced into the evacuated cell by evaporation from liquid water, which had been admitted to a previously evacuated small glass bulb. The water vapor passed through a

packless valve and a short piece of copper tubing; evaporation was accelerated by gently heating the bulb and the adjacent valve and tubing. The water vapor was allowed to remain in the cell with the valve closed until adsorption was "complete"; i.e., until for a constant cell temperature measured values of p no longer showed variations. Various amounts of nitrogen were then added to produce total pressures P as high as one atmosphere. Dew point measurements showed no appreciable variations in p as long as the cell temperature remained constant. This result indicates that the addition of nitrogen had no significant influence on water vapor adsorption. In order to detect possible slow variations, samples were allowed to remain in the absorption cell overnight without observable change in dew point or in total absorptance provided measurements were made at the same temperatures.

Much of the present work was done during the summer months when the ambient temperature of the laboratory varied considerably during the day. In view of the adsorption–desorption effects accompanying temperature variations, it was necessary to monitor the partial pressure frequently during the course of a run by making dew point measurements.

In view of the present results, the HBW assumption that adsorption is not seriously influenced by the addition of nitrogen would appear to be valid. Fortunately, most of the HBW measurements were made during a period of the year when the laboratory temperature did not vary over wide ranges; their use of the massive 22-meter absorption cell probably further minimized temperature variations, which the present study showed to give spurious effects. Comparison of the present total absorptance results with those of HBW in similar ranges of w and P_e indicated that in general the two sets of data agreed within the limits of experimental error.

The data and results obtained in the present study are presented in a manner similar to those used in the earlier papers in the present series except for the use of a different unit (pr. cm) for absorber concentrations. Some of the curves presented are based on both the present results and the HBW data. Values of equivalent pressure were calculated for each sample from the relation $P_e = P + 4p$, where P is the total pressure and p is the partial pressure of water vapor. This relation is based on a value $B = 5$ for the self-broadening coefficient of water vapor; the measured value[4] $B = 5 \pm 1.5$ is in fair agreement with values obtained in other recent studies.[7–9] The "effective pressures" employed in the original HBW work correspond to an equivalent pressure based on $B = 2$, a value considerably lower than those obtained in more recent studies.

Experimental Results

Representative plots of spectral absorptance of water vapor in the vicinity of the 5332 cm^{-1} band are shown

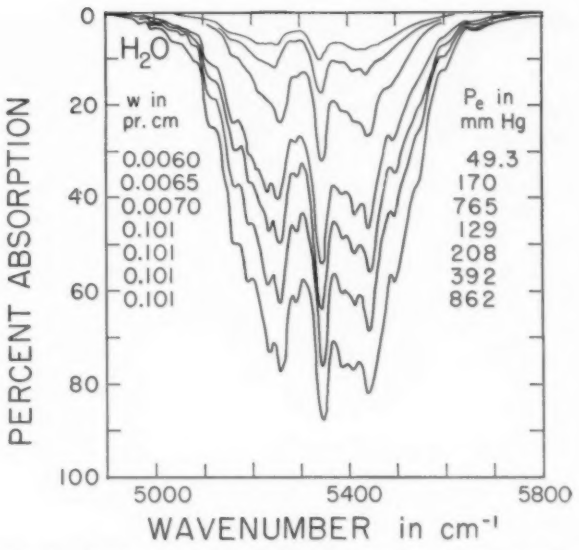

Fig. 1. Spectral absorptance in the vicinity of the 5332 cm^{-1} band of water vapor. The effective slit width employed was 20 cm^{-1}.

in Fig. 1; the values of w and P_e for each of the curves are indicated in the figure. The effective slit width employed was 20 cm^{-1}; forty-two runs for different samples were made during the present study. The estimated uncertainties in values of $\int A(\nu)d\nu$ are ± 6 to $\pm 8\%$ for values of $\int A(\nu)d\nu$ greater than 50 cm^{-1}, and somewhat larger for smaller values of $\int A(\nu)d\nu$. The accuracy of $\int A(\nu)d\nu$ for the other two bands is approximately the same.

The curves in Fig. 2 give logarithmic plots of $\int A(\nu)d\nu$ for the 5332 cm^{-1} band as a function of w for various values of equivalent pressure. The curves in this figure are based on the 42 runs made in the present study, together with earlier HBW data; present results were in the range of small w and the HBW results were

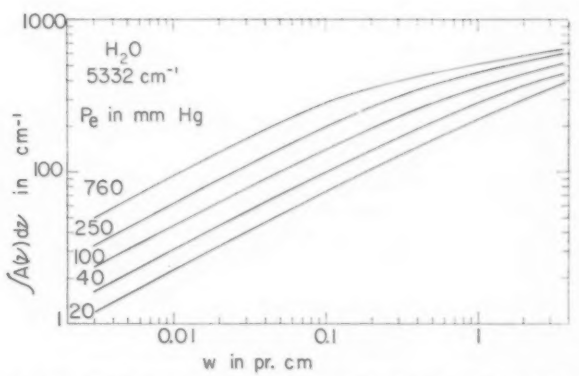

Fig. 2. Total absorptance $\int A(\nu)d\nu$ of the 5332 cm^{-1} band for various values of equivalent pressure P_e as a function of absorber concentration.

chiefly in the range of large w. Over the small range of w in which the two sets of data overlapped, there was agreement in corresponding values of $\int A(\nu)d\nu$ to ± 5 to $\pm 10\%$ for most values of P_e; this agreement is considered satisfactory in view of the estimated experimental errors listed above; the agreement might be considered excellent in view of the fact that the range of overlap is the range in which the HBW values are least accurate because the samples were smallest. Comparison of the present results with those obtained in the early work of Chapman and Howard is much less favorable; values of $\int A(\nu)d\nu$ for similar samples often differed by as much as 20 or 30%.

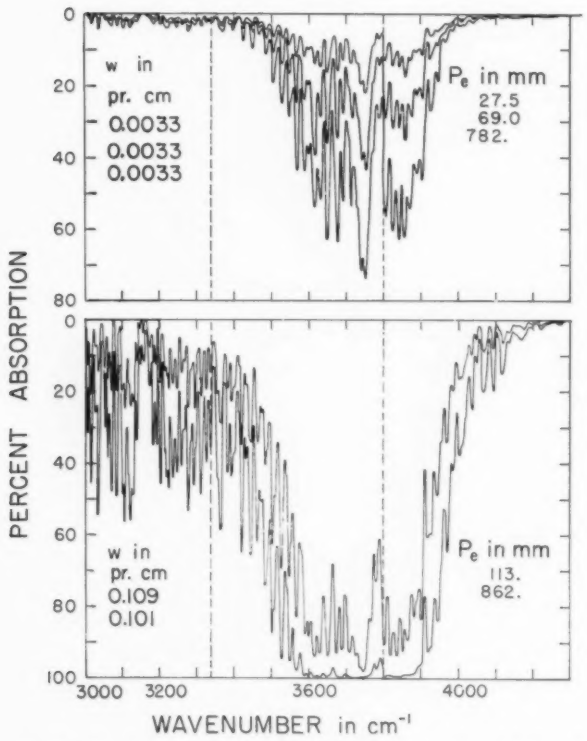

Fig. 3. Spectral absorptance of water vapor in the vicinity of the strong bands near 3700 cm^{-1}. The effective slit width was approximately 10 cm^{-1}.

In view of the improved experimental techniques employed in the present work, the present results were given "extra weight" in determining the positions and shapes of the curves shown in Fig. 2, which are believed to represent best all the data obtained in the present and in the HBW investigations. Values of $\int A(\nu)d\nu$ for given values of P_e and w as given by the curves are believed to be valid to $\pm 6\%$. The same accuracy is estimated for the corresponding plots for the other bands.

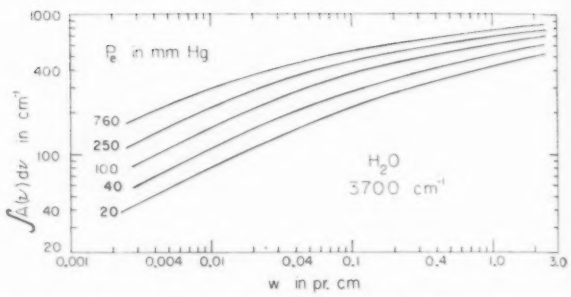

Fig. 4. Total absorptance $\int A(\nu)d\nu$ of the 3700cm^{-1} water band for various values of equivalent pressure P_e as a function of absorber concentration w.

Spectral absorptance records in the vicinity of the 3700 cm^{-1} band are shown in Fig. 3; values of w and P_e for each curve are indicated. The effective slit width employed was 10 cm^{-1}. Forty-six "runs" were made in the region of the 3700 cm^{-1} band. The dashed vertical lines in the figure represent arbitrary boundaries of "subregions"[3]; values of $\int A(\nu)d\nu$ for each subregion were tabulated for possible future use but are not given in the present article. Total absorptance of samples having various values of P_e is plotted as a function of w in the logarithmic plots of Fig. 4; the plotted values of $\int A(\nu)d\nu$ include all absorptance in the 3340 to 4300 cm^{-1} region but do not include the weak $2\nu_2$ band in the 2800 to 3340 cm^{-1} region. The curves in Fig. 4 give the best plot of present and HBW results.

Spectral absorptance curves in the vicinity of the 1595 cm^{-1} band of water vapor are shown in Fig. 5, in which values of w and P_e are indicated; the spectral slit width employed was 6 cm^{-1}. The dashed vertical

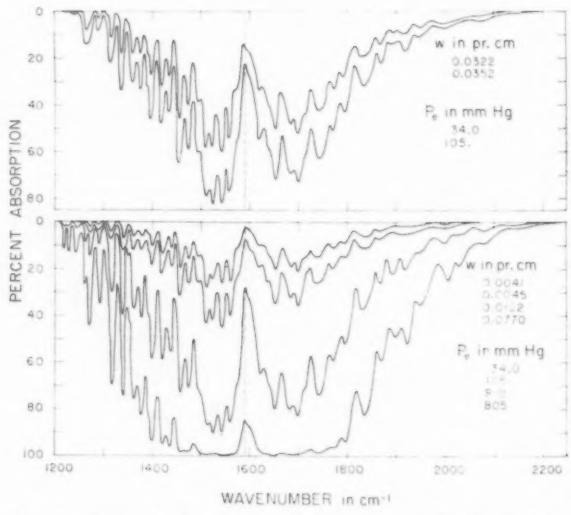

Fig. 5. Spectral absorptance of water vapor in the vicinity of its ν_2 fundamental at 1595 cm^{-1}. The effective slit width was approximately 6 cm^{-1}.

line at 1590 cm^{-1} represents an arbitrary boundary between two subregions, for each of which $\int A(\nu)d\nu$ was tabulated for possible future use. Plots of $\int A(\nu)d\nu$ for the entire 1595 cm^{-1} band for various values of P_e as a function of w are shown in Fig. 6. As in the case of the other bands, the curves in Fig. 6 represent the best estimates that can be made on the basis of the present data—thirty-three runs—and the earlier HBW data.

It is possible to develop empirical equations expressing $\int A(\nu)d\nu$ in terms of P_e and w for each of the water vapor bands studied. However, it is believed that more accurate estimates of the total absorptance to be expected for a sample of known w and P_e can be obtained by interpolation between the curves shown in Figs. 2, 4, and 6 than by the use of empirical equations having limited ranges of validity. Extrapolations of the plots in the figures to ranges of P_e and w not actually covered in the experimental work should be avoided.

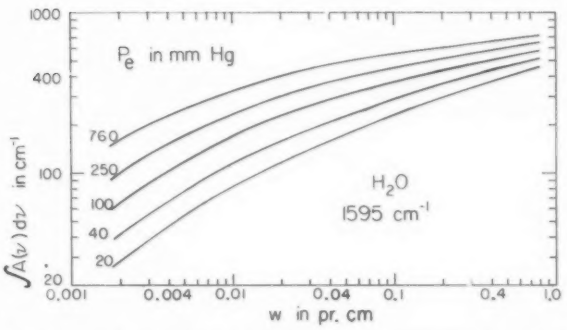

Fig. 6. Total absorptance $\int A(\nu)d\nu$ of the 1595 cm^{-1} band for various values of equivalent pressure P_e as a function of absorber concentration w.

The authors wish to express their appreciation to John H. Shaw for his suggestions regarding the use of dew point techniques for determining the partial pressures of water vapor, and to William Beard and Jorgen W. Birkeland for their help during certain phases of the investigation. The use of library facilities of the Institut d'Astrophysique at the Université de Liège during the preparation of the present paper is also gratefully acknowledged.

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Books *continued from page 584*

Advances in Glass Technology. Compiled by the American Ceramic Society. Plenum Press, New York, 1962. 639 pp. $21.00.

A bound book collecting all technical papers of the Sixth International Congress on Glass—the first to take place in the United States—was available to its participants at its starting hour. This great effort of volunteers did not only greatly facilitate the preparation of a discussion in some depth of the selected topics of glass science and engineering presented, but has also made available to students, institutions, and industries an up-to-date cross section of information of reasonable coherence. This coherence, it is true, is in part a consequence of necessary restrictions due to the tremendous cost of simultaneous translation which, at least in this country, precludes parallel sessions in most instances. However, it certainly contributes greatly to the reading value of this book, which would not necessarily be expected from the mere recording of a Glass Congress. (See also page 604 of this issue.)

The selected topics are balanced between fundamental, applied, and engineering studies (48 in total). Major titles are: Structure, Diffusion Phenomena, Properties of New Glasses, Principles of Melting and Forming Processes, Mechanical Properties, and Glass Metal Interfaces. The present treatment of glass *structure* has departed from classical techniques, such as x-ray diffraction, which has delivered by and large general and average structural features. The presentations at the Congress emphasize techniques that permit one to look at singularities which affect structure and properties more than had been believed recently: nuclear magnetic resonance, electron spin resonance, Rayleigh scattering, gamma-ray induced defect centers, discontinuities in glass formation ranges. In all respects the methods of solid-state science that are applied to crystals have now penetrated the investigation of noncrystalline solids. In relation to constitutional studies the investigation of *diffusion phenomena* has become significant enough to fill a separate session. The understanding of the behavior of "water" or "dissolved protons" in glass has greatly increased. The new knowledge has benefited infrared applications as well as fundamental problems. The behavior of helium, with a much smaller "chemical" relation to the glass structure, is described in contrast. The diffusion of alkali (and, occasionally, Ag or Cu) in glass is the topic of numerous investigations because of its broad significance to phenomena as unrelated as electrical properties, dealkalization of surfaces, alkali vapor attack on special glasses, formation of color centers in filter glasses, etc.

A focus of attention at the meeting—and most likely on reading the book—is formed by the series of studies under the heading of *properties of new glasses*. In some papers—as in several that will, as "brief research announcements," follow in a second volume, together with the complete discussion of the papers in this first volume—the practical value of the new uses has unfortunately somewhat curtailed the depth of treatment. Nevertheless, there will be enough to encourage the informed reader, to proceed in the development and conceptual analysis of the

less conventional materials; electrical semiconducting and conducting glasses, glasses of high contents in transition elements, nonoxide glasses of very low softening point (sulfide–selenide–telluride–halide glasses), and last, not least, the important class of entirely, mostly, or partially crystallized glasses in which the formation and shaping method belongs to glass technology, but properties are contributed by crystalline arrangements. A highlight among the new materials, described by S. D. Stookey and co-workers of pyroceram renown, is a glass of ultrahigh strength, developed by crystallizing a surface layer, which in one type was obtained by ion exchange. Glass is now also an important competitor among scintillation counter materials.

In the engineering group the book is distinguished by the discussion of various practical problems usually limited to off-the-record conferences. The American locale of the Congress has brought a fertile accumulation of such material to the fore. In the section on *melting and forming principles* are treated corrosion, volatilization, solid reactions, and bubbles. The present Japanese theory on the latter takes—in this reviewer's opinion pertinently—issue with accepted concepts. Less conventionally, there are papers on models of continuous melting, electrical, and vacuum melting. In the discussion of *mechanical properties* one notices that the content of the 1961 Symposium in Florence—at which principles were brilliantly established and recorded—tends to generate detailed rather than revolutionary findings. In the same way the excellent contribution on polishing glass from France derives from the recent and exhaustive Paris Symposium. The third engineering theme, *metal-glass interactions* during conditioning and forming, contains studies on heat transfer but also specific reactions such as those of mobile alkali ions in glass and of fluxes containing fluorine, and an analysis of the reactions of glasses of various composition at the iron–glass interface.

An appendix contains committee reports of the International Commission on Glass which is the sponsoring organization of the Congresses: one on temperature distribution and one on heat transfer in glass tanks.

A tremendous progress has been made in the appearance of the economical printing process (composition by justifying typewriter and offset printing) that was used in a specialist presentation of this type in which over 600 pages and hundreds of illustrations are offered to the glass people of all nations.

The volume is fittingly dedicated to Howard R. Lillie of Corning Glass Works who represented the American Ceramic Society on the International Commission since 1950 and was the President of the Commission from 1959 to his untimely death in an accident en route to a meeting concerned with the organization of this Congress. The attractive volume will be valued in the increasing circle of those concerned with the expanding use of novel glasses and the workers in applied solid-state science for whom the noncrystalline solid is no longer out of bounds. G. Rindone of Pennsylvania State University mentioned in the function of an editor on page XVI and his co-workers deserve commendation for this accomplishment. It is suggested that the editor or editors rather than just a Society should appear on the title page of books of this character.

N. J. KREIDL

The Mechanism of Glass Polishing. By D. C. CORNISH. British Scientific Instrument Research Association, Research Report R 267 (1961). Published by British Scientific Instrument Research Association, Sira, South Hill, Chislehurst, Kent, England. 70 pp. $7.00.

This report is a history and bibliography of glass polishing. No experimental work is reported, although it is stated that one of the fundamental research projects presently being carried out by the British Scientific Instrument Research Association is an investigation into the nature of glass polishing.

The section entitled "History of the Theories of Glass Polishing" begins with Hooke, who in 1665 wrote of his ideas on the polishing of glass surfaces. Other early workers who recorded their views on the subject include Knuckel (1679) and Newton (1695). These early records indicate that the polishing process was looked upon as a continuation of the grinding process on a smaller scale. It was not until 1901 that Rayleigh came to the conclusion that the two processes were different. Soon afterwards Beilby proposed a new mechanism, which was, in essence, that polishing was the result of surface flow. The formation of a Beilby layer, as it is now known, constitutes one of the theories still widely held not only in regard to the polishing of crystals and glass but also of metals.

Since then many reports of work on the polishing of glass have been published in Europe, including Russia, in America and in Japan. In the 1930's it was said that there were three distinct theories of polishing: 1) Polishing was a microgrinding process in which the glass was removed by a pitting or cutting and grooving action of the polishing grains on a scale too small to appear visible by means of photo-optics; 2) The polish was achieved as a result of plastic deformation of the surface with glass removed to, and filling up, the hollows. Removal of glass by the grains themselves was incidental except in so far as it produced fine grooves that were then immediately filled by surface tension forces acting on the flowed layer. Alternatively, there need be no loss in weight, the polish being effected entirely by redistribution of material; and 3) The surface actually became molten under the intense local pressures involved with subsequent solidification to form an amorphous film. The chemical aspects of polishing were noted, including the effect of water both in liquid and vapor form, the reactions of a colloidal nature, the effects of adsorption, and the reactions between the surface being polished, the water, and the polishing agent. Thus opinions on the polishing process became even more divided.

Through the nineteen-fifties various improved techniques were used to study the polishing process. These included phase-contrast and electron microscopy, multiple-beam interferometry, small-angle x-ray studies, and radioactive tracers. The conclusions drawn from this review of history seem to be that any one or any combination of several processes are involved in the production of the polish (or leveling). The contribution of each of these mechanisms to the whole process under various conditions remains to be determined.

The bibliography, listing 279 papers, is divided into four sections: 1) Mechanism of Glass Polishing; 2) Surface Properties of Polished Glass; 3) Polishing Agents; and 4) Lap Materials. Fairly comprehensive abstracts of many papers under each heading are given, but these are uncritical and it is left to the reader to evaluate each of them. An author index is also given.

GIVEN W. CLEEK

Have you read the Russian maser papers in OPTICS AND SPECTROSCOPY?

The Reflection and Transmission of Infrared Materials: I, Spectra from 2 50 Microns

Donald E. McCarthy

The reflection and transmission of fifteen commonly used infrared optical materials have been measured to 50 μ with a Beckman IR-7 with CsI optics. Using these reflection properties, small inexpensive reststraalen filters have been constructed. By applying a fine grind to reststrahlen plates, it is shown that stray light can be reduced in far-infrared instruments.

Introduction

In the design of infrared systems, the transmission and reflection of optical materials must be well known to select the best window or prism material for a particular wavelength region. These properties are also useful in constructing economical filters. All of the materials presented in this paper have been examined before; some in part, others completely in the 2–50 μ region. Usually, the information is scattered throughout different journals and many years. One purpose of this work is to make available in one place, transmission and reflection data on the most commonly used infrared optical materials. New information is also included.

A series of papers giving the physical properties of infrared optical materials has been published by Ballard, Combes, and McCarthy. Much of these data has been compiled in a University of Michigan report by Ballard *et al.*[2]

Experimental

Spectra from 2–50 μ were obtained for every material presented here. A Beckman IR-5A was used in the 2–16 μ region; while in the 12.5–50 μ region, a Beckman IR-7 with a CsI interchange was used. This consisted of a 48° CsI foreprism with a 30 line/mm grating, blazed at 30 μ. The grating was used in the first and second orders. A Beckman thermocouple with a CsI lens served as the detector. Reflection measurements were made with a Beckman specular reflectance attachment and compared to an aluminum mirror. The angle of incidence in all cases was 30°.

All materials were ground and polished to a flatness of seven fringes or better on both sides, except silicon and germanium. These were flat to within one fringe.

No coating was applied to the materials on either front or back surface, so any contribution to reflection measurements from the back surface is purely specular.

Results

The materials reported here are all synthetic and the reflection spectra are identical with those of natural crystals wherever comparison can be made with previous measurements. Some slight differences in the transmission of synthetic and natural quartz have been observed around 3 μ. These differences amount to a 5% increase in intensity of the 2.8 μ band and an 8% decrease in the 2.95 μ band. Both values refer to the synthetic material.

In Figs. 1 through 14, the dotted line refers to the transmission and the solid line to the reflection. The sample thickness follows the name of the material in the title. The numbered references may be found in Part II* of this article.

Sodium Chloride

NaCl (Fig. 1) can be used effectively as a prism material to about 16 μ. It has a reststrahlen band at 52 μ, as measured by Rubens,[74] Mitsuishi,[63] and Czerny.[28] Hass[39] reported the temperature dependence of this reststrahlen band. The refractive index of NaCl has been reported by Coblentz.[27] Absorption measurements have been published by Langley,[50] Rubens,[78] and Barnes.[18] NaCl is hygroscopic and must be protected from excessive humidity.

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Part of this paper was presented at the 1961 Annual Meeting of the Optical Society of America in Los Angeles, California.

* Appl. Optics **2**, 596 (1962).

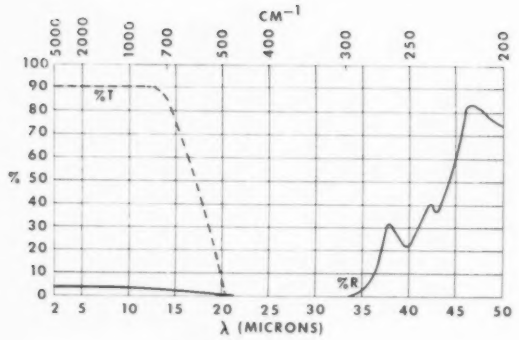

Fig. 1. NaCl, 5 mm.

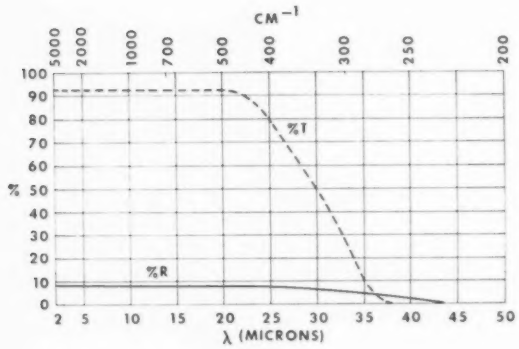

Fig. 2. KBr, 5 mm.

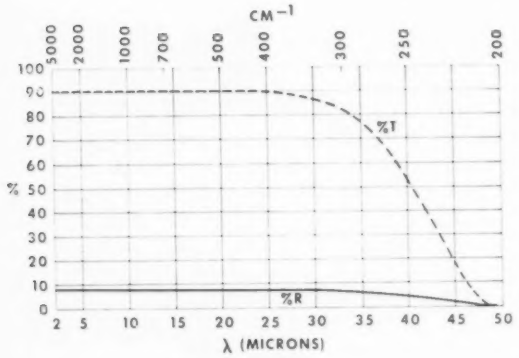

Fig. 3. CsBr, 1 cm.

Potassium Bromide

KBr (Fig. 2) is useful as a prism material to 25 μ. Its reststrahlen band appears at 79 μ.[97] Like NaCl, it is hygroscopic and must be used in a dry atmosphere. Gundelach,[94] Korth,[98] and recently Stephens,[102] have measured the refractive index. Transmission measurements have been reported by Forrest.[92]

Cesium Bromide

CsBr (Fig. 3) is also hygroscopic. It extends the prism region to 35 μ, and its reststrahlen band is at 120 μ.[107] Transmission measurements have been reported by Plyler and Phelps[105] and Menzies.[104] Rodney and Spindler[106] have published values of the refractive index.

Cesium Iodide

CsI (Fig. 4) represents the present limit to prism spectroscopy in the infrared. It can be used as a prism to 50 μ. Like other alkali halide materials, CsI is hygroscopic. Contrary to popular belief, CsI is mechanically stable. Prisms of this material, under a pressure of 53 g/cm^2 (0.75 lb/in.^{2}), have been used in Beckman IR-7's for three years, and no evidence of flow or change of shape has occurred. Rodney[112] has presented data on the refractive index, while Plyler measured its transmission.[110] Its reststrahlen band appears at 145 μ.[111]

Quartz

SiO_2 (Fig. 5) was one of the first materials used for infrared spectroscopy. Its reflection was measured by Merritt,[137] Nichols,[140] and Carvallo[116] in the 1890's. It has two large reststrahlen bands at 9 and 21 μ. Nichols did much of the work in finding reststrahlen bands at longer wavelengths; investigating such materials as

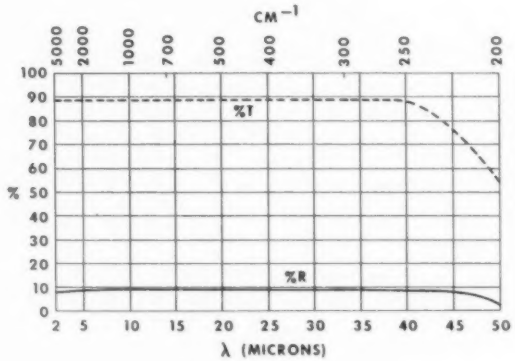

Fig. 4. CsI, 1 cm.

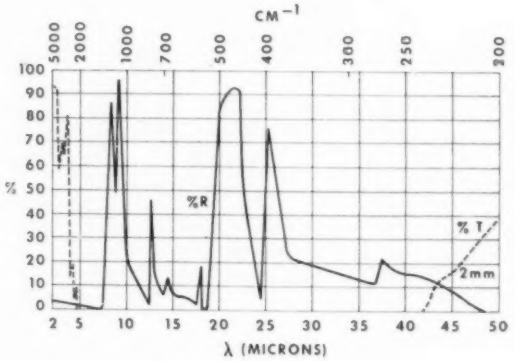

Fig. 5. Quartz, 1 cm.

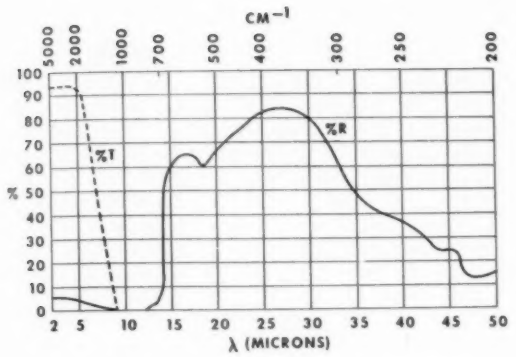

Fig. 6. LiF, 5 mm.

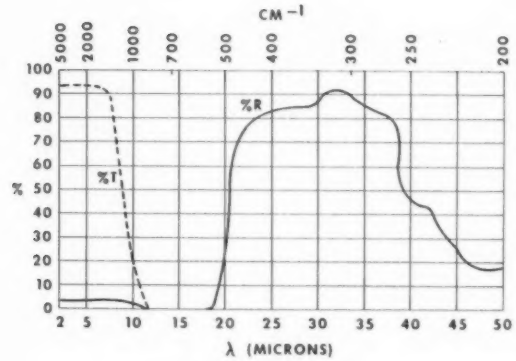

Fig. 7. CaF_2, 5 mm.

quartz, NaCl, and CaF_2. One of the earliest measurements of the transmission of quartz was done by Coblentz[117] in 1906. He also determined its index of refraction, which was redone by Coode-Adams[124] in 1927 and by Ramadier-Delbes.[146] As can be seen from Fig. 5, quartz starts to transmit again around 45 μ. Thin pieces of quartz, which serve as filters to cut out stray light from the near infrared, have been used as windows and lenses on thermocouples and cells for the far infrared.

Lithium Fluoride

The refractive index of LiF (Fig. 6) has been measured by Hohls in 1937,[184] by Littman in 1940,[189] and by Durie[176] in 1950. The reflectivity of LiF was first reported by Korth[188] in 1932 and by Tilton[197] in 1951, who extended the index of refraction measurements. Heilmann[183] and Gottlieb[180] also reported on the reflectivity. Gottlieb's[181] work in 1960 compared the reflectivity of LiF and isotopically enriched samples of LiF. Deubner[175] and Stevenson[196] measured the transmission of LiF.

Calcium Fluoride

CaF_2 (Fig. 7) was another material that was used in the early days of infrared spectroscopy. Rubens and Snow[74] measured its reflectivity in 1892 and Carvallo[199] its refractive index in 1893. Paschen[206] in 1913 and Rubens[157] in 1916 did some more work with it, followed by Malitson[200] in 1961. In 1959, Wichersheim[213] reported some work on the infrared absorption of CaF_2.

Sapphire

The transmission and reflectivity of sapphire (Fig. 8) has been reported by Ballard.[2] In 1961, Loewenstein[216] measured the transmission of this material in the far-infrared region (10–80 cm^{-1}). The index of refraction has been measured by Malitson *et al.*[217] Sapphire is used mainly as a window for cells and detectors, or as a substrate for filters.

Arsenic Trisulfide

As_2S_3 (Fig. 9) is a glass that was reintroduced in 1950 by Frerich.[220] Measurements of the refractive index were reported by Malitson *et al.*[222] Components made from it must be handled carefully, preferably with rubber gloves, to prevent poisoning.

Silver Chloride

Schroter[232] did some work on the refractive index of AgCl (Fig. 10) in 1931, which was followed by Hyde[228]

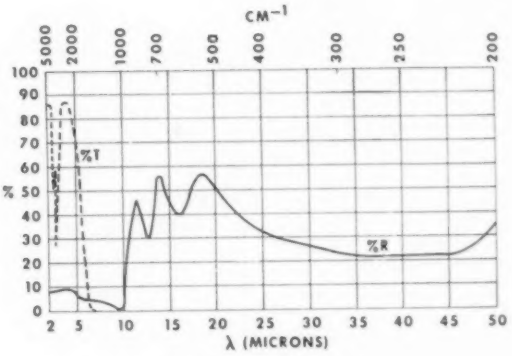

Fig. 8. Sapphire, 2 mm.

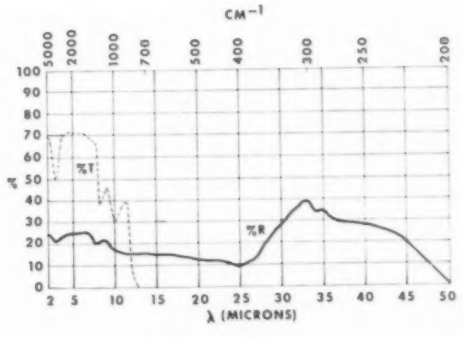

Fig. 9. As_2S_3, 5 mm.

in 1947. In 1950 Tilton *et al.*[233] of the Bureau of Standards, measured the refractive index from 0.5 to 20 μ. Kremers[230] has measured the transmission from 2 to 25 μ, while reflection measurements in the 70–140 μ region have been made by Jones.[97] It is a pliable material which darkens, resulting in decreased transmission, when exposed to radiation of 0.5 μ or less.

Thallium-Bromide Iodide

KRS5 (Fig. 11) was developed in Germany during the 1940's. Tuttle[245] did some work on it in 1946 and Plyler[241] reported using it as a prism material from 24 to 40 μ. Because of its higher reflection losses and shorter wavelength range, it is not as good a prism material as CsI. The refractive index as reported by Hettner[236] for KRS5 made in Germany is about 100 $\times$ 10^{-4} higher in index than that measured by Tilton[244] for American-made KRS5. Tilton ascribes this to a larger percentage of thallium iodide in the German material. Its reflectivity has been measured by McCubbin[239] in the 60–220 μ region.

Irtran I

Irtran I (Fig. 12) is a trade name of pressed sintered magnesium fluoride.[246] As can be seen, it has two large reststrahlen bands at 20 and 39 μ.

Irtran 2

Irtran 2 (Fig. 13) is pressed sintered zinc sulfide. The refractive index from 2 to 14 μ of ZnS was reported by Hall[249] and the reflectivity measured by Sinton[120] and then by Yoshinaga[327] from 20 to 200 μ.

Silicon

The first reported work on silicon (Fig. 14) was by Ingersoll[283] in 1910. But the real emphasis came with the advent of semiconductor research; Becker and Fan[252] in 1949, and Briggs[256] in 1950, followed by a host of others, measured the absorption properties. Index of refraction measurements were given by Briggs[255] and extended by Simon.[322] Lord[297] measured the transmission between 2 and 40 μ and Kahn[285] extended this to 50 μ. In 1955, Yoshinaga[327] measured the reflectivity from 20 to 200 μ. There is a considerable number of papers dealing with doped, irradiated, or stressed effects on the infrared transmission of Si.

Germanium

Ge (Fig. 15), like silicon, is of great interest to people doing semiconductor work and many papers have been published concerning it. Sutherland[326] in 1948, Becker and Fan[252] in 1949, and Brattain and Briggs[254] did some of the early work. Lark-Horovitz[296]

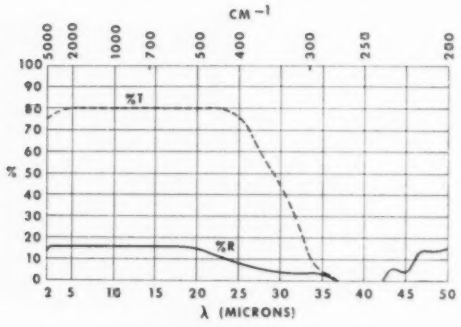

Fig. 10. AgCl, 0.5 mm.

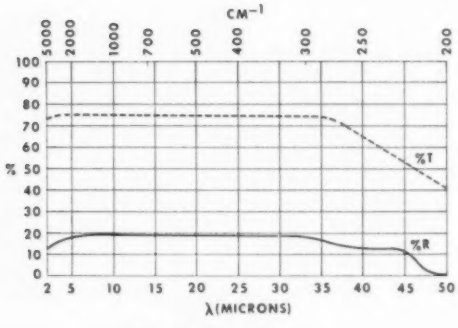

Fig. 11. KRS5, 2 mm.

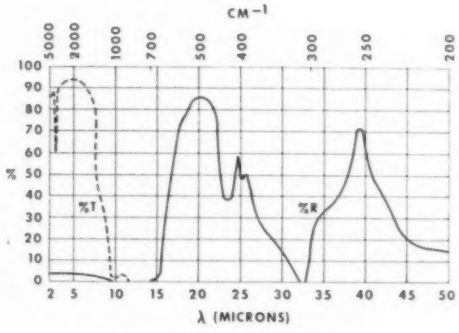

Fig. 12. Irtran 1, 2 mm.

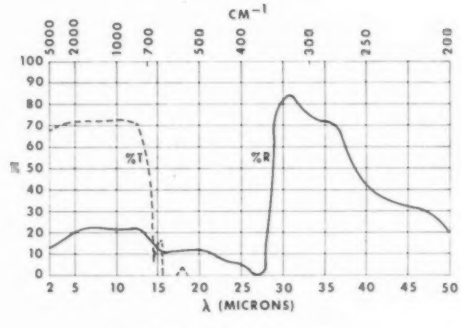

Fig. 13. Irtran 2, 1 mm.

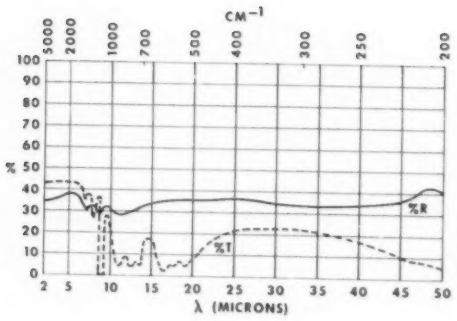

Fig. 14. Silicon, 1 cm.

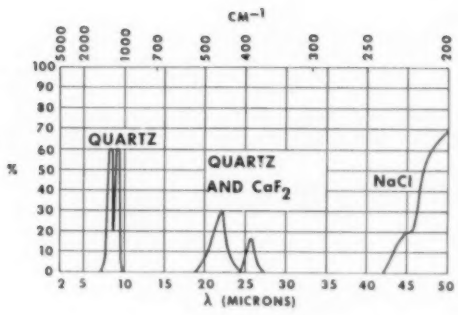

Fig. 16. Reflection filters.

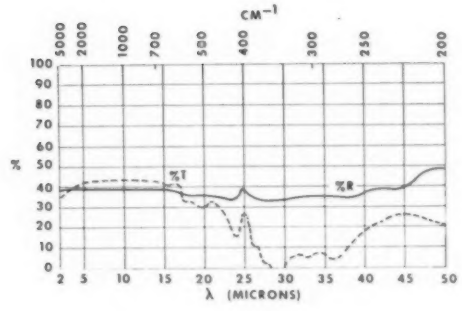

Fig. 15. Germanium, 1.6 mm.

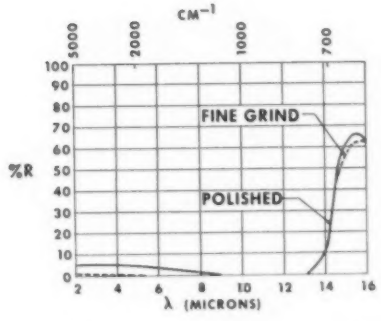

Fig. 17. Effect of grinding on surface reflection.

measured its reflectivity from 8.7 to 15 μ, using reststrahlen bands. Values of the index of refraction from 1 to 2.6 μ have been reported by Briggs[255] and from 2 to 16 μ by Salzberg and Villa.[320]

By combining the reflection properties of some of these materials, it is possible to construct relatively narrow band reststrahlen filters (Fig. 16) to cover regions where no interference filters are available or are too costly. If the aluminized roof prism of a Beckman 30° specular reflectance attachment is replaced by an uncoated quartz prism, and a quartz plate is placed in the sample position, only the 9 and 21 μ bands are reflected with about equal intensity. Placing a window of CaF_2 after the reflection attachment, the 21 μ band is eliminated. Then, removing the quartz plate and placing the CaF_2 plate in its position to act as a reflector, eliminates the 9 μ band and leaves the 21 μ band of the intensity shown in Fig. 16. A 52 μ filter can be obtained by using three surfaces of NaCl. The size of the complete unit is 7.5 × 5 × 5 cm. Other materials can be used that have good strong reststrahlen bands. These filters can be mounted on the face of a blackbody source to determine the spectral response of thermal detectors.

The maxima of these reststrahlen bands are temperature dependent[39] and spectra should be measured at the temperature at which they will be used.

If a material such as LiF or CaF_2 is used to give a wide band reststrahlen filter for far-infrared studies, 4% reflected energy from the shorter wavelengths can easily equal the energy in the region under study. If a polished plate of LiF is compared (Fig. 17) to the same plate after a fine grind is put on it (dotted line), the intensity of the specularly reflected short-wavelength radiation is reduced to less than 1%, yet the curves are identical beyond 16 μ.

In summary, gaps in the reflection and transmission of 15 commonly used infrared materials have been filled; using this information about the optical properties, narrow band reststrahlen filters have been constructed, and by applying a fine grind to reststrahlen plates, stray light can be reduced in far-infrared instruments.

Bibliography *follows*

The Reflection and Transmission of Infrared Materials: II, Bibliography

Donald E. McCarthy

The papers in this bibliography give data on the infrared reflection and transmission of fifteen optical materials. Index of refraction papers are also included. The papers are listed according to material and are arranged alphabetically by the first author in each section.

This bibliography includes those papers which have been published in scientific journals that give data on the reflection and transmission of optical materials in the infrared region. Papers dealing with index of refraction measurements are also included. The materials covered are NaCl, KBr, CsBr, CsI, Quartz, LiF, CaF_2, Sapphire, As_2S_3, AgCl, KRS5, Irtran I, Irtran II, Si, and Ge.

The bibliography is split into sections; the first is on general references that give information on many materials. The following sections deal with a particular material. Papers are arranged alphabetically in each section by the first author and numbered consecutively throughout. Numbered references are given at the end of each section that refer to other papers in the bibliography that pertain to a particular material. The Irtran I and II sections are labeled Magnesium Fluoride and Zinc Sulfide, respectively, because the Irtrans are pressed sintered forms of MgF and ZnS.

Part I of this report [Appl. Opt. **2,** 591 (1963)] contains spectra on the reflection and transmission of these materials from 2 to 50 μ. A discussion of each material points out the most useful references in this bibliography.

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See also, ref. 167.

Meeting Reports *continued from page 570*

Edgerton. Considerable factual information was given on actual lamps, in terms of expected life with the curves ending abruptly at a life of *one flash*. End of life of a specific lamp can be caused by (1) explosion due to peak loading; and (2) wear of the electrodes and (3) evaporization of the quartz walls all causing a reduction in the light output. It was shown how the life of a flash lamp can be increased if the flash duration is extended since the damage is a function of the peak current.

Fischer, together with Gallagher and Tandy, gave additional information on the Fischer capacitor and electrode combination for producing a short intense small flash light. Improvements in the mechanical and electrical design have made possible a spark source with a rise time of about 1.1 μsec and a half-width of about 5 nsec. A Fischer gap was on display in the exhibit of the Impulsephysics Association.

A spark gap over a semiconductor, titanium dioxide, was on display in the scientific exhibit by Moden, Reese, and Pooley of England. Sound as well as light was greatly in evidence when the 4.5 μF low-inductance capacitor charged to 5 kV was suddenly discharged. Many details of the time variation of light and current, with gap distances and voltage, were given in a paper. No triggering method of the gap had been devised at the time of presentation.

Vollrath showed a most interesting spark light source, consisting of a modern piezoelectric generator which converted the energy of a mechanical shock wave into an electrical pulse. A simple cinematographic setup is thus possible from a small quantity of explosive by allowing the compression wave to trip successively a sequence of crystals, each with a gap.

Papers on rotating mirror cameras and their application were numerous. Also, there were many papers concerning Kerr cells and image converters and x-rays. All of these papers will be published as has been mentioned previously.

First Czechoslovak Conference on Infrared Radiation, Brno, November 13–15, 1962

Reported by A. Vaško, Laboratory of Optics, Czechoslovak Academy of Science, Prague

The First Czechoslovak Conference of infrared techniques and their applications in science and industry considered, in addition to scientific and technical matters, problems of planning. (The program of the conference did not include the application of infrared spectroscopy in chemistry.) The conference was attended by 126 scientists and technologists, and forty-six papers, reports, and communications were delivered. At the plenary sessions, the following papers were read: A Review of Physics and Techniques of Infrared Radiation (A. Vaško), The Development and the Present State of Infrared Techniques in Czechoslovakia (J. Doubek), Detection of Infrared Radiation (R. Novák), Infrared Amplification by Stimulated Emission of Radiation (J. Doubek), and A Review of Direct and Indirect Infrared Photography (J. Schlemmer). The main work of the conference was concentrated in five sections which dealt with physics of infrared radiation, elements of infrared technology, infrared instruments, application of infrared techniques in the natural sciences and medicine, and infrared heating.

There were exhibits demonstrating infrared instrumentation developed in CSSR. There was also a display of many original infrared photographs from the various fields of science and technology.

The conference passed a resolution formulating the aims of future scientific research and proposing certain measures to promote successful development in the infrared field in Czechoslovakia.

Sixth International Congress on Glass, Washington, D. C., July 8–14, 1962

Reported by Alvin J. Cohen, Mellon Institute

This triennial meeting, sponsored by the International Commission on Glass with the cooperation of the American Ceramic Society, was attended by almost six hundred participants from twenty-three countries. One of the highlights of the meeting was the presentation to each participant upon registration of a bound volume of all the invited technical papers that were presented. This volume is entitled *Advances in Glass Technology* and is published by Plenum Press, New York (see page 589 of this issue). The book is dedicated to Howard R. Lillie who lost his life in an airplane crash near Brussels on February 15, 1961, while enroute to a meeting of the Executive Committee of the Commission. Much of the success of the Congress in Washington was due to Dr. Lillie's efforts, and his loss was felt by all attending the Congress. The volume contains forty-eight of the technical papers delivered at the Congress.

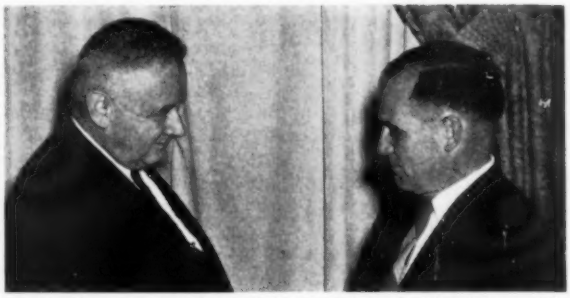
One session of technical papers on July 9th was devoted to presentation of brief research announcements of five minutes duration. The varied subjects were semiconductivity, dielectric losses, electron microscope investigations, ligand field theory, lasers, and electrical conductivity, all in glasses or silicates. Further brief topics presented during the Congress were on Griffith's flaws, heat treatment, relaxation of torsional stress, photosensitive glasses, immiscible glasses, glass color striking, multiple break sources, infrared spectra, surface nucleation in fibers, radial distribution studies, electron spin resonance in quartz, viscosity, density, and electrical resistivity determinations of molten borates, and hardness impressions on glass. The afternoon session was composed of invited papers on glass melting. Concurrent sessions were held on the history of glass. These covered such interesting topics as the evolution of processes for hand fashioning of window glass from the tenth century, history of the glass industry in Japan, and problems of research in Polish glass in the early middle ages. During these technical sessions, the ladies visited either the Belgian or Japanese Embassy.

During the technical sessions on July 10th, papers were presented on magnetic resonance studies in glasses, Rayleigh scattering in glass, color centers in glass, and glass structure. An afternoon session was held on process principles in continuous melting of glass and a concurrent session on diffusion phenomena in glass. The history sessions also continued and were concerned with the history of Czechoslovakian glass, Egyptian fused miniature mosaics, eighteenth century ingots of glass, Lauenstein glasses, glass collections of the U.S. National Museum, and glass details in ancient architecture and furniture. The history session participants spent the afternoon at the U.S. National Museum reviewing a special glass exhibit.

The technical sessions on July 11th covered new glasses containing major proportions of transition metal oxides, arsenic-sulfur-halogen glasses, electrical conducting glasses, complex phosphate glasses and germanium glasses, alkali-alumina glasses, glasses from basic eruptive rocks, high-strength glasses, cerium containing glasses, photosensitive glasses, glass scintillators, and oriented borosilicate glasses.

During all sessions the papers were simultaneously translated into either English, French, or German. Each participant could dial the language translation desired on small transistor radios equipped with earphones. The history sessions on July 11th had papers on the contributions of sociology of glass, use of antimony and manganese in ancient glass, analyses of ancient glass, electron probe microanalyses of ancient glass, and fossil glasses produced by meteorite and asteroid impact, opacifying agents in oriental glass, etc. The last day of technical sessions saw papers on the mechanical properties of glass and metal-glass interactions during conditioning and forming.

Several glass journals had special issues for the Congress. Among these were the *American Ceramic Society Bulletin*, *European Glass* published by Verlag des Sprechsaal, and *Bohemian Glass* by the *Czechoslovak Glass Review*. A second volume on the history papers given at the Congress will be published in the near future.



M. Herzberger, 1962 Ives Medalist and D. L. MacAdam, 1962 OSA President, both authors of papers in this issue.

REFEREES

The following people referee papers submitted to APPLIED OPTICS from time to time, and the Editors wish to acknowledge with gratitude this service:

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Empirical Methods for Computing the Integrated Absorptances of Infrared Bands of Atmospheric Gases at Nonuniform Pressures

J. H. Shaw

Methods are described for computing the total absorptances of bands of atmospheric gases in solar spectra based on (1) empirical relationships between total absorptance and absorber concentration and equivalent pressure for homogeneous mixtures of the absorbing gas and a broadening gas and (2) relationships obtained for two samples of gas. The variation of the atmospheric heating rate with pressure due to the absorption of solar radiation by such bands is estimated, and it is shown that for bands in the solar spectrum due to gases with a constant mixing ratio, an effective pressure $\bar{P} = {}^1/_2 P_0$ can be used with an error of less than 5%.

There are many applications for which a knowledge of the absorption of infrared radiation by the atmosphere is required. In a cloud-free atmosphere this absorption is predominantly caused by bands of a number of atmospheric gases, including H_2O, CO_2, N_2O, O_3, CH_4, CO, and O_2; and the atmospheric absorption coefficient at any frequency for a given path depends upon the concentrations of these gases and the atmospheric pressure and temperature. In the vicinity of absorption bands, this coefficient varies rapidly with frequency; hence, although the fine structures of many bands have been studied in great detail, there are many examples of atmospheric paths whose absorption of radiation is difficult to predict with confidence.

Many estimates of atmospheric absorption have been based on the experimental measurements of the integrated absorptance by entire bands of gases made by Howard *et al.*,[1] Burch and Williams,[2] and Burch *et al.*[3] described in this journal and *J. Opt. Soc. Am.* The total absorptance of a band $\int A(\nu)d\nu$ is defined as the spectral absorptance $A(\nu)$ of the band at frequency ν integrated over the spectral region occupied by the band. The term absorptance $A(\text{cm}^{-1})$ will be used to describe this quantity in this paper.

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The laboratory measurements were made on well-mixed samples of the absorbing gas and a broadening gas, usually N_2, at a uniform pressure, and these authors have described the dependence of the band absorptances on the absorber concentration w(atm cm N.T.P.) and equivalent pressure (P_e mm Hg) both by graphs and by empirical expressions that are valid for certain ranges of the sample parameters. For many bands, provided P_e is not too great, these expressions have the forms

$$\text{(Type I bands)} \quad A = C[w(P_e)^a]^b \text{ for } x_1 < w(P_e)^a < x_2 \qquad (1)$$

and

$$\text{(Type II bands)} \quad A = D \log [w(P_e)^a] + E \text{ for } x_2 < w(P_e)^a < x_3, \qquad (2)$$

where C, D, E, a, and b are empirical constants, with $0.5 < a < 1.0$ and $b \sim 0.5$. The equivalent pressure is defined as

$$P_e = P + (B - 1)p,$$

where P is the total pressure of the absorbing gas and the broadening gas N_2; p is the partial pressure of the absorbing gas; and B, the self-broadening coefficient, is the ratio of the self-broadening ability of the absorbing gas to the broadening ability of N_2. For many atmospheric calculations, $p << P$ and $P_e \sim P$. The range of sample parameters for which Eq. (1) is valid may be described as the square-root region. If the band consisted of lines with a Lorentz shape and the absorber concentration were sufficient to produce complete absorption at all the line centers, then

$$A = f[(wP_e)^{0.5}],$$

and, for the case where there is no line overlapping,

$$A \propto (wP_e)^{0.5}. \quad (3)$$

These expressions are similar to Eqs. (1) and (2) when $a = 1$ and $b = 0.5$. In the following discussion, bands that can be described by expressions of the form of Eq. (1) will be classed as Type I bands. Type II bands are those whose absorptances follow expressions similar to Eq. (2).

The relations in Eqs. (1) and (2) were obtained from measurements of gas samples at a uniform pressure, and they cannot be used directly to calculate the absorptances of bands of gas samples whose pressures vary along the absorbing paths. Instead, various modifications based on the known structures of the bands and the line shapes have been proposed. Houghton[4] and Mureray *et al.*[5] have, for example, shown that by plotting the experimentally determined absorptances obtained by Howard *et al.*[1-3] as a function of (wP_e) rather than $w(P_e)^a$, then, provided the total pressure is small, the absorptance can be described by relations similar to Eqs. (1) and (2), where $a = 1$ and $b = 0.5$. However, inspection of the original laboratory data shows that, even at pressures less than 250-mm Hg, this gives an oversimplified description of the pressure dependence. Thus, although these simplified expressions have been used to predict the absorptances of bands of atmospheric gases that occur in solar spectra in the lower stratosphere, they cannot be used with confidence to predict the absorptances in the troposphere. Alternate methods of modifying the more general relations in Eqs. (1) and (2) are required to calculate the absorptances of the bands in these regions of higher atmospheric pressures.

Gryvnak and Shaw[6] have proposed a method for calculating absorptances by Type I bands in solar spectra based on laboratory measurements of the absorptance of the 4.7-μ CO band for the case where continuous radiation was passed through two samples of the gas; data also have been obtained for the 4.5-μ N_2O band.[7] For both of these bands, there is a range of absorptances for the two samples, for which

$$A = C'[w_1(P_{e1})^{a'} + w_2(P_{e2})^{a'}]^{b'}, \quad (4)$$

where subscripts 1 and 2 refer to the individual samples. This expression accurately represents the experimental data, provided the greater part of the combined absorptance occurs in one sample chosen so that its absorptance can be described by an expression similar to Eq. (1). The constants C', a', and b' agree with the values C, a, and b in the corresponding expression for a single sample.

Abels[7] has also found that, for larger total N_2O concentrations, there is a range of absorptances for the 4.5-μ band for two samples, which could be described by

$$A = D' \log [w_1(P_{e1})^{a'} + w_2(P_{e2})^{a'}] + E'. \quad (5)$$

The ranges of absorptances and equivalent pressures for which Eq. (5) can be used are approximately the same as the ranges for which Eq. (2) is valid for a single sample. Further, although the values of D' and E' in Eq. (5) differ somewhat from the values for D and E in Eq. (2), nevertheless, for the case with $w_2 = 0$, the absorptance by a single sample w_1 predicted by Eq. (5) is in excellent agreement with that found experimentally.

The success of describing the dependences of the absorptance of a band of N_2O and a band of CO on the physical conditions of two gas samples in series suggests that these results can be extended to describe the absorptance of other bands not only of these gases, but of others for the case in which radiation passes through two gas samples. In particular, the absorptances of CO_2 bands that have line spacings ($\sim$1.6 cm^{-1}) intermediate between those of CO ($\sim$4 cm^{-1}) and N_2O ($\sim$0.8 cm^{-1}) should be accurately described by such expressions. Further, if initially continuous radiation passes through more than two gas samples or through a gas sample whose pressure and absorber concentration vary continuously, it is reasonable to expect that there will be a range of conditions for which the band absorptances will be given by

$$\text{(Type I bands)} \quad A = C[\Sigma P_i^a w_i]^b = C[\int P^a dw]^b, \quad (6)$$

and

$$\text{(Type II bands)} \quad A = D \log [\Sigma P_i^a w_i] + E = D \log [\int P^a dw] + E, \quad (7)$$

where the constants are those determined empirically for single samples at a uniform pressure and the ranges of absorptances are similar to those for which Eqs. (1) and (2) hold. The summation forms are useful, for example, for computing the absorptances of water-vapor bands along atmospheric paths of varying water-vapor mixing ratio. The absorptances by bands of gases with a constant mixing ratio can be obtained from the integral forms of Eqs. (6) and (7).

Applications

Absorptances by Bands of Atmospheric Gases in Solar Spectra

In an isothermal atmosphere at temperature T, the pressure at height h is

$$P = P_o \exp(-h/H), \quad (8)$$

where P_o = surface pressure (mm Hg),

$$H = RT/Mg,$$

and $M = 29$, is the mean molecular weight of the atmosphere. If an absorbing gas has a constant mixing ratio m in such an atmosphere the amount traversed between h and $h + dh$ by solar radiation passing through the atmosphere at an angle θ to the vertical is given by

$$dw = H_s m \sec\theta dp/P_s = T_s P m \sec\theta dh/(P_s T), \quad (9)$$

where $P_s = 760$ mm Hg, $T_s = 273°$K, $H_s = RT_s/Mg \sim 8 \times 10^5$ cm, and the curvature of the earth is neglected.

If $P_o = P_s$, the absorptances of Type I and II bands at height h in the atmosphere are found from Eqs. (6), (7), (8), and (9) to be

$$\text{(Type I bands)} \quad A_h = A_1 \exp[-b(a+1)h/H], = A_1(P/P_s)^{(a+1)b}, \quad (10)$$

where

$$A_1 = C[H_s m \sec\theta/(a+1)]^b P_s^{ab}; \quad (11)$$

$$\text{(Type II bands)} \quad A_h = A_2 - 0.434\, D(a+1)h/H = A_2 - D(a+1)\log(P_s/P), \quad (12)$$

where

$$A_2 = D \log[H_s m \sec\theta P_s^a/(a+1)] + E. \quad (13)$$

Thus, the absorptances of Type I bands are exponential functions of height and vary much more rapidly than the absorptances of Type II bands, which are proportional to altitude.

Since expressions of the form of Eqs. (1) and (2) are available for many bands of atmospheric gases which are observed in the solar spectrum, it is possible to use these together with Eqs. (10) and (12) to compute the variation of the absorptance of these bands with height. A comparison of the absorptances of the 4.3-μ CO_2 band and the 4.5-μ N_2O band is given below. Both of these bands are intense in ground-level solar spectra and appreciable overlapping occurs. This overlapping is neglected in the following discussion.

4.3-μ CO_2 Band

Howard *et al.*[1] have found that the absorptance of this band by a single sample of gas is given by

$$A = 34 \log[w(P_s)^{0.93}] + 27.5, \quad (14)$$

provided $75 < A < 225$ cm^{-1}. A generally accepted value[4] for the mixing ratio of CO_2 is 3.1×10^{-4}. The ground-level absorptance of the 4.3-μ CO_2 is then found, from Eqs. (13) and (14), to be 190.3 cm^{-1} for the case where $\theta = 0$. The absorptance at height h (km) in an isothermal atmosphere at 273°K is given by Eq. (12), which reduces to

$$A_h = 190.3 - 3.53h. \quad (15)$$

4.5-μ N_2O Band

The following expressions can be derived from the data of Abels and the analysis given above to describe the absorptance of this band by a sample of N_2O at a nonuniform pressure.

$$A = 48 \log[\int P^{0.7}\, dw] + 9 \quad (16)$$

for

$$45 < A < 85 \text{ cm}^{-1},$$

and

$$A = 18.2\,[\int P^{0.7} dw]^{0.54} \quad (17)$$

for

$$10 < A < 45 \text{ cm}^{-1}.$$

The results of Rank *et al.*[8] and Birkeland and Shaw[9] indicate that the mixing ratio of N_2O in the atmosphere is constant and approximately equal to 2.7×10^{-7}. If solar radiation is incident vertically, then Eqs. (13) and (16) give a value of A_2 of 62.8 cm^{-1}. Thus,

$$A_h = 62.8 - 4.43\, h \text{ (km)}, \quad (18)$$

provided

$$A_h > 45 \text{ cm}^{-1} \text{ and } h < 4.0 \text{ km}.$$

Above 4 km Eqs. (10), (11), and (17) give

$$A_h = 73 \exp(-0.115\, h) \quad (19)$$

for $H = H_s$, $\theta = 0$, and h in km.

In Table I, the absorptances of the CO_2 and N_2O bands computed from Eqs. (15), (18), and (19) are given.

It is seen that the CO_2 band has the greater absorptance at all altitudes; but, whereas the ratio of the absorptances is 3:1 at the surface, it increases to 40:1 at 30-km altitude. If the method described by Houghton[4] is used, the absorptance of the 4.3-μ CO_2 band in ground-level solar spectra for an isothermal atmosphere with an equivalent height H_s and $\theta = 0$ is 194 cm^{-1} and 74 cm^{-1} at 30-km altitude. This agreement with the values given in Table I may be expected, since both calculations are based on the same experimental data, and the rate of change of absorptance of Type II bands with altitude is small. Although accurate values of the absorptances of these bands cannot be obtained from the solar spectra obtained by Shaw *et al.*[10] at ground level or from the spectra obtained by Houghton *et al.*[11] at various altitudes, the estimated values are not in disagreement with those given in Table I.

Estimates of the absorptance by the CO_2 bands at 2.7 μ in solar spectra can also be obtained from the data of Burch *et al.*,[3] using both the method described by Houghton and that described in this paper.

Table I. Absorptances of the 4.5-μ N_2O Band and the 4.3-μ CO_2 Band in Solar Spectra

Ht (km)	$A_h(CO_2)$ (cm^{-1})	$A_h(N_2O)$ (cm^{-1})
0	190	63
4	176	45
10	155	23
15	137	13
20	120	7
25	102	4
30	84	2

It is found that the variation of absorptance with height is approximately proportional to pressure in both cases. However, Houghton's method predicts an absorptance in close agreement with the calculated absorptances given by Mureray *et al.*,[5] whereas the present method predicts absorptances approximately 2.5 times greater at all pressures. Since the observed absorptances of these bands at altitudes up to 28.6 km are smaller than any of those predicted, it is difficult to draw any satisfactory conclusions from these comparisons. There appear to be few other experimental data with which to compare the absorptances predicted by the methods described in this paper.

Atmospheric Heating Rates

The heating rate dT/dt (°K sec^{-1}) at a pressure level p(mm Hg) due to the direct absorption of solar radiation by an absorption band is

$$\frac{dT}{dt} = \frac{7.6 \times 10^{-4} g}{c_p} B_\nu \frac{dA}{dP} = G \frac{dA}{dP},$$

where

$$G = \frac{7.6 \times 10^{-4} g B_\nu}{c_p}$$

and

c_p = specific heat of air at constant pressure (J g^{-1} °K^{-1}),

B_ν = intensity of solar radiation in the frequency interval occupied by the band (W cm^{-2} wave number^{-1}).

The heating rates of Type I and Type II bands at a pressure level P for a gas with a constant mixing ratio in the atmosphere are found by differentiation of Eqs. (10) and (12):

$$\text{(Type I bands)} \quad \frac{dT}{dt} = GA_1(a+1)b\left(\frac{P}{P_s}\right)^{a+1b-1}, \tag{20}$$

$$\text{(Type II bands)} \quad \frac{dT}{dt} = \frac{GD(a+1)}{P}. \tag{21}$$

The heating rate of a Type II band is independent of the mixing ratio and is inversely proportional to pressure, but is a much more complicated function of pressure for a Type I band. For the particular case of Type I bands whose absorptance is described by Eq. (3), the heating rate is independent of pressure. However, the dependence on pressure is also quite small for many of the bands studied by Howard, Burch *et al.*[1-3] For example, the heating rates of the 4.7-μ CO band and the 4.5-μ N_2O band, in the region where their absorptances can be described by Type I expressions, are proportional to $p^{0.01}$ and $p^{-0.08}$, respectively. If the pressure dependence is neglected for such bands, then Eq. (20) reduces to

$$\frac{dT}{dt} \sim GA_1(a+1)b.$$

Effective Pressure

Although the absorptances of bands of atmospheric gases may be calculated from expressions of the form of Eq. (10) or (12), it is also useful to describe the band absorptance of an atmospheric path in terms of an effective pressure. If all of the absorbing gas in a given atmospheric path were at a uniform pressure, then the effective pressure is that required to give the same absorptance as the atmospheric path. A widely used expression for the effective pressure for an isothermal atmospheric path is

$$\bar{P} = \frac{\int P dw}{\int dw}. \tag{22}$$

If solar radiation is absorbed by a band of a gas with a constant mixing ratio, Eq. (22) can be evaluated to give

$$\bar{P} = XP_b,$$

where $X = 0.5$ and P_b is the pressure at the lowest level penetrated. This relationship may be used with many theoretical-band models, but no verification of its accuracy has been made when applied to atmospheric bands. Other expressions for the effective pressure may be determined for Type I and Type II bands from Eqs. (1), (2), (10), and (12). For the case in which solar radiation is being absorbed by a gas with a constant mixing ratio, it is found for both types of bands that

$$\bar{P} = XP_b \tag{23}$$

where

$$X = (1+a)^{-1/a}.$$

For the particular case in which the absorptance is given by Eq. (3), or when a is equal to 1, then X has the value of 0.5, in agreement with Eq. (22). However, Howard, Burch *et al.*[1-3] have found that $0.5 < a < 1.0$ for a number of bands of atmospheric gases. For this range of values, the dependence of X on a as given by Eq. (23) is quite small. For example, when a has values of 0.75 and 0.50, then X is 0.475 and 0.445, respectively. Hence, $P = 0.5\ P_b$, the effective pressure predicted by Eq. (22), can be used with an error of less than 5% for these ranges of a. Under these conditions, from Eqs. (1), (2), and (9),

$$\text{(Type I bands)} \quad Ah = C\left[\frac{H_s\, m \sec\theta}{2^a P_s}\right]^b P^{(a+1)b},$$

and

$$\text{(Type II bands)} \quad Ah = D \log\left[\frac{H_s\, m \sec\theta}{2^a P_s} P^{a+1}\right] + E$$

are useful approximate expressions for the absorptances

of bands in the solar spectrum of gases with a constant mixing ratio at a pressure P in an isothermal atmosphere with a sea-level pressure of 760 mm Hg.

The author wishes to thank J. T. Houghton for many useful discussions and to express his appreciation for the use of the library and other facilities of the Department of Atmospheric Physics, Oxford, during the preparation of this paper.

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Thomas B. Dowd *ONR*, Stanley S. Ballard *President OSA*, and Walter S. Baird *Chairman Membership Committee OSA*, during the IRIS Fall Meeting.

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2. J. Culpeper, *Space Optics* (Georgetown Institute of Technology Press, Washington, D.C., 1861), pp. 12, 345.

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There will be no **page charge** for publishing in *APPLIED OPTICS* for the time being.

Letters to the Editor should follow the above suggestions, but no abstract is required.

OSA Around-the-World Group Flight 1964

Revised Information

The International Commission for Optics Symposium on Photographic and Spectrographic Optics will be held in Tokyo 1–8 September 1964, preceded by a Conference on Interference and Coherence convened under the auspices of the ICO and the Australian Academy of Science in Sydney, 23–29 August 1964. The airlines have recently approved an around-the-world group flight fare for 15 persons or more, and OSA, even at this early date, is interested in learning the number of members who are potentially interested in attending these two meetings and participating in this group flight. It is also hoped to have an informal gathering in Israel (say 13–17 August), and perhaps something similar in India (say 18–19 August). It appears better for our purpose to finish this around the world trip in the Orient (rather than to start it there as had been our original intent), so our revised—but still tentative—schedule now looks like:

		From	To	Purpose
Aug. 8	lv. 10:00 pm	NYC	London	
9	arr. 9:35 am		London	
11	lv. 11:55 am	London	Athens	
	arr. 4:20 pm		Athens	
13	lv. 7:20 pm	Athens	Tel Aviv	
	arr. 9:20 pm		Tel Aviv	informal colloquium?
17	lv. 9:25 pm	Tel Aviv	New Delhi	
18	arr. 9:10 am		New Delhi	
19	lv. 12:15 pm	New Delhi	Bangkok	
	arr. 5:15 pm		Bangkok	
21	lv. 6:05 pm	Bangkok	Singapore	
	arr. 8:40 pm		Singapore	
22	lv. 9:30 pm	Singapore	Sydney	
23	arr. 9:35 am		Sydney	ICO Interference and Coherence Meeting—(Sessions 24–25, visits to lab. 26–27, visits outside Sydney 28–30
31	lv. 10:05 am	Sydney	Tokyo	
31	arr. 11:40 pm		Tokyo	
Sept. 1–8				ICO Mtg. Tokyo & Kyoto on Photographic and Spectroscopic Optics
8	lv. 11:15 pm	Tokyo	Honolulu	
8	arr. 11:40 am		Honolulu	
10	lv. 11:30 pm	Honolulu	San Francisco	
11	arr. 7:15 am		San Francisco	
11	lv. 8:30 am	San Francisco	New York	

The group fare would be approximately $1150 economy class round trip. Only OSA members and their immediate relatives may participate. Would members who are potentially interested (there is no commitment) fill in and return this form. The interest of those who have already written in is recorded.

Assistant Secretary, OSA
Room 101
1155 Sixteenth Street, N.W.
Washington 36, D.C.

REPLY

I am interested in principle in participating in the OSA 1964 AROUND-THE-WORLD GROUP FLIGHT, and I wish to have information as it becomes available.

☐ I would travel alone ☐ accompanied by my wife ☐ my children (state how many)

Name..... OSA Membership Number.....

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.....

.....

Direct Recording of Integrated Band Intensities from a Linear Wavelength Spectrometer

B. Schurin, D. E. Williamson, and S. A. Clough

Instrumentation that allows direct recording of integrated band intensities from a double-beam spectrometer is described. A potentiometer is geared directly to the linear wavelength drive of the spectrometer and used to servo the chart drive of a strip-chart recorder so that a linear wavenumber scale is produced. A maximum scan of 2 μ is possible, the 2 μ being located at the operator's discretion in the 4–18 μ range of the spectrometer. A logarithmic potentiometer has been incorporated into the recorder to convert the transmittance data into optical density units while the integration is carried out with a continuous ball-and-disk integrator.

Introduction

For experiments designed to measure the vibration-rotation band intensities of simple molecules we have constructed an apparatus that allows direct recording of such intensities from a high-resolution infrared spectrometer.

The spectrometer[1] is characteristic of many of the more recently designed instruments in that the grating is connected to a lead screw through a sine bar mechanism which produces spectra linear in wavelength. When the spectrometer is operated as a double-beam instrument the result is a continuous chart recording of the transmittance (I/I_0) as a function of wavelength from which the normal spectral data of line and band positions are obtained. For the corresponding intensity measurements, however, the quantity required is $\int \log (I_0/I) d\nu$, where ν is the wavenumber, $\log (I_0/I)$ is the optical density of the sample, and the integration is carried over the entire vibration-rotation band.

Even for simple molecules, bands are distributed over a large spectral range and may vary widely in their spectral widths. The problem requires that there be flexibility in the choice of spectral region and that the nonlinear relation between wavelength and wavenumber does not cause unnecessary compression or expansion of the wavenumber scale. On the other hand, there are no serious restrictions on the range of optical densities to be measured. In fact, theory requires that measurements be made in the linear or low-density region.[2]

Normally the data conversion is performed manually, and a procedure for such point-by-point treatment of the data has been described by Arends and Eggers.[3] In the best circumstances this represents the sum of many tedious operations. For an extended program of measurements, there is considerable advantage in being able to utilize the continuous recording aspect of the spectrometer.

Wavenumber Drive

Principle of Operation

A simplified wavenumber drive is presented in Fig. 1. The potentiometer R_1 is geared directly to the rotating shaft of the grating drive so that $\Delta R_1/\Delta\lambda$ is a constant. The current through the left-hand branch will be proportional to ν if $[(R_k + R_1)/\lambda_b] = R_k/\lambda_a$. If R_k is taken outside the potentiometer, then $E_k = IR_k$ is available as a reference voltage which varies as ν.

The paper-drive pot in the right-hand branch is geared directly to the chart paper movement. The indicated follow-up servo moves the paper-drive pot in a direction to balance E_2 against the reference voltage E_k. Under these conditions, the paper-drive moves linearly with ν as it follows the reference voltage E_k.

For a fixed paper-drive pot resistance, the span control determines the voltage drop across the resistor and hence the amount of chart paper per unit wavenumber change. The zero control allows the initial balance to be set. With these two values fixed, the

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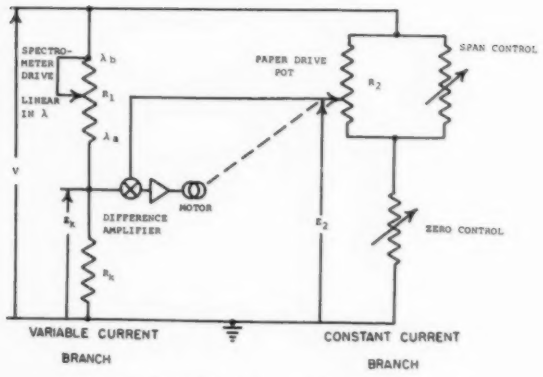

Fig. 1. Simplified wavenumber drive circuit.

right-hand branch will have constant current during the scanning operation.

Variable Current Branch

The operating circuit is shown in Fig. 2. We have geared a 10,000 Ω, 0.1%, 40-turn Helipot potentiometer (R_1) to the drive of the instrument. The potentiometer reaches zero wavelength with 180 Ω still remaining on the potentiometer. The resistance change is 545.5 Ω/μ in first order, and the operating range of the spectrometer in first order is taken to be 3–18 μ.

Since we do not go below 3 μ in first order, there are 1636 Ω of winding that can be removed and used externally. This is done by placing a tap on the Helipot as indicated in the circuit. We must add 180 Ω in determining the location of the tap since 0 μ is not at zero resistance. Column 5 of Table I gives the values of resistance taps that are made from this external resistance. The values for R_k have been chosen so that the change in voltage over each of the 2-μ spans is a constant. This is shown in col. 7 which is obtained from the products of cols. 4 and 5. Column 8 gives the values of the resistors and is obtained by subtracting each value of R_k from the value next high in resistance.

The choice of a 2-μ span is an arbitrary compromise that satisfies the requirement that the wavelength scale is not excessively compressed or expanded. For instance, if the range 3–15 μ were to be covered in a single span, with a design center of 40 cm of chart between 5 and 6 μ, then the chart would be 180 cm between 3 and 4 μ and 5.6 cm between 14 and 15 μ.

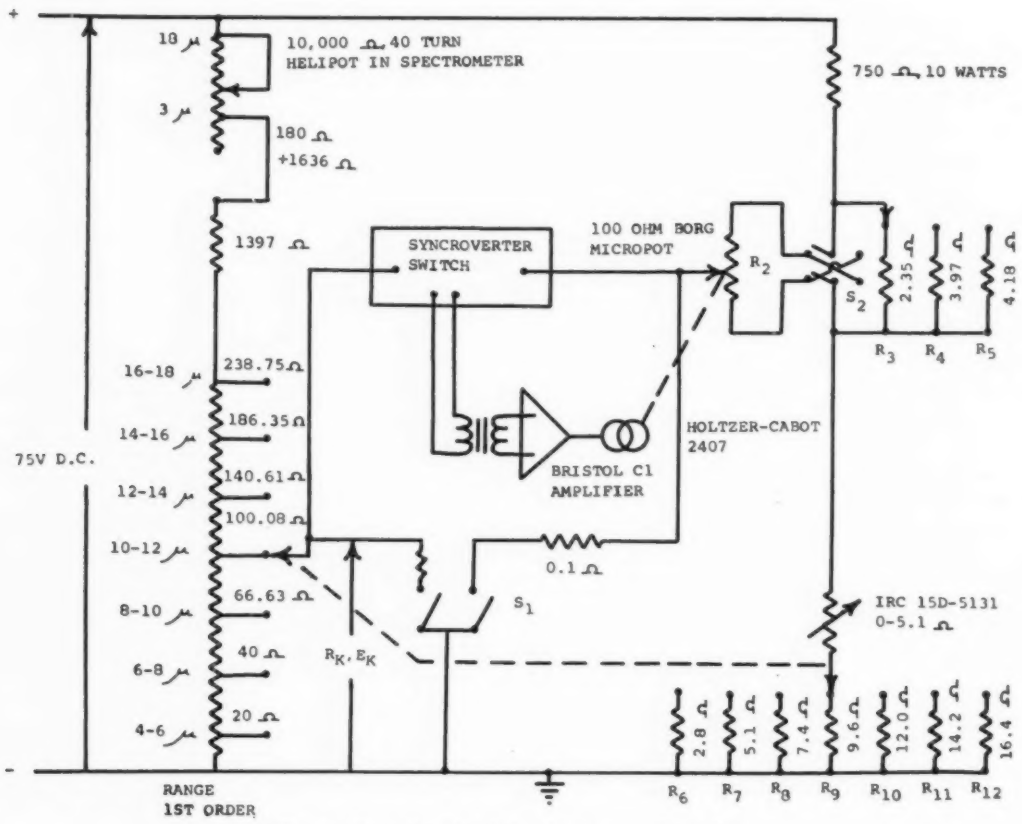

Fig. 2. Operating circuit for the wavenumber drive.

Table I. Circuit Calculations for the Voltage Branch, Assuming 75-V Supply

Column Number	1st order (1) λ(μ)	(2) R	(3) I(mA)	(4) ΔI(mA)	(5) R_k	(6) E_k	(7) ΔE_k	(8) ΔR_k (Resistor values)
Not on tap sw	(3)	(1636)	(45.8)			0.917		
	4	2182	34.37					
				11.26	20	0.4582	0.230	20
	6	3273	22.91					
				5.73	40.00	0.6872	0.230	20
	8	4364	17.18					
				3.44	66.63	0.9156	0.230	26.63
	10	5455	13.74					
				2.29	100.08	1.1459	0.230	33.45
	12	6546	11.45					
				1.63	140.61	1.3837	0.230	40.53
	14	7637	9.82					
				1.23	186.35	1.6007	0.230	45.74
	16	8728	8.59					
				0.96	238.75	1.8216	0.230	52.40
	18	9819	7.63					
						1636 − 238.75 = 1397.25		

Column Number	A 2nd order	B Set 1st order	C Scan 1st order	D R_k	E E_k	F 3rd order
	2–4	4	4–8	20	0.3438	
Design ctr	3–5	6	6–10	40	0.3668	2–3.33
2nd order	4–6	8	8–12	66.63	0.3818	2.66–4
	5–7	10	10–14	100.08	0.3923	3.33–4.67
Design ctr	6–8	12	12–16	140.61	0.4021	4–5.33
3rd order	7–9	14	14–18	186.35	0.408	4.67–6

Constant-Current Branch

E_k is compared with the voltage from the potentiometer operated in the constant-current circuit. The voltage span of this potentiometer should equal the change in voltage (ΔE_k) shown in col. 7. This is accomplished by shunting R_2 with resistances R_3, R_4, and R_5. The value of R_3 is chosen to make the drop across the potentiometer 0.230 V. (R_4 and R_5 are calculated for operation in second and third order.) For any of the designated 2-μ ranges, the follow-up servo will cause the potentiometer R_2 to move from one end of its range to the other, and hence for a 2-μ span a given gearing ratio in the paper drive of the recorder will result in the same length of paper regardless of the spectral region chosen.

Consider operation in the 4–6-μ if range. If the spectrometer proceeds toward longer wavelengths, the current in the voltage branch of the circuit will decrease and as a consequence the voltage E_k becomes smaller. This means that the follow-up servo will be driving the potentiometer slide downward toward smaller voltages. When the spectrometer has reached 6 μ the current in the voltage branch is 22.91 mA, and the product of the current and the resistance R_k (20 Ω in this case) results in an E_k of 0.4582 V. This voltage is given in col. 6 of Table I for the longer wavelength end of each 2-μ span.

This voltage must, in each case, appear between the bottom end of the potentiometer R_2 and ground, and it therefore must appear across the resistors labeled R_6 and R_{12}. These resistances consist of a fixed and a variable resistance, the variable resistance having a total range of 5 Ω. In addition to allowing for precise balancing at the beginning of a run, the variable resistance also allows overlap on the ends of the range.

If the direction of spectrometer scan is reversed, the switch S_2 corrects the change in chart-drive motion.

Higher Orders

The bottom portion of Table I refers to second- and third-order operation. For second-order operation, we again required a 2-μ span from 4 to 6 μ. In order to scan from 4 to 6 μ in the second order (col. A), it would be necessary to scan the instrument from 8 to 12 μ in the first order (col. B). If the wavelength selector switch were set on the 8–10 μ range, the value of R_k from col. 5 would be 66.63 Ω (col. D). The values of current in the voltage branch at the 8- and 12-μ points are 17.18 mA and 11.45 mA. The difference is 5.73 mA, which when multiplied by 66.63 Ω (R_k) gives a ΔE_k of 0.3818 V. This voltage must appear across R_2 to satisfy our criterion and to determine R_4. In a similar manner R_5 was chosen for third-order operation.

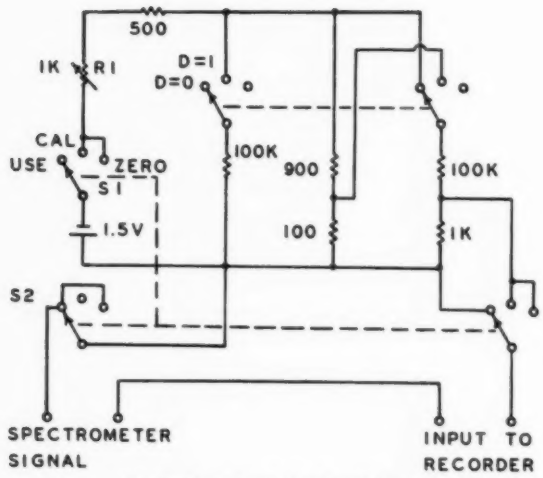

Fig. 3. Calibration circuit for logarithmic recorder.

The second- and third-order shunt resistances can also be used to compress the range of the recorder. If the range were set from 4 to 6 μ in first order, and the order switch placed on third order, the voltage across the potentiometer would be 0.4021 V, which is almost twice the value given in col. 7 for the change in E_k. Thus the wavelength span will be almost doubled for the same paper length.

Servo and Chart Drive

The reference voltage E_k is connected to the chart-drive potentiometer R_2 through a simple follow-up servo identical to the unit used in the potentiometer circuit of the Bristol recorder. Since the chart drive is no longer operating synchronously, the chart-drive motor in the recorder has been replaced with a Holtzer-Cabot 2407 servo motor having a 60:1 gear reduction and an approximate speed under full load of 20 rpm.

The design center for the paper drive of the recorder is such that approximately 40 cm of paper will correspond to 1 μ in the range from 5 to 6 μ when the gearing of the recorder is set for the slowest paper speed. The recorder is provided with change gears that give a total range of 16:1. By interchanging the gears having the largest ratio (4:1), the 40-cm 1-μ record can be spread out to 650 cm for 1 μ. This is the only mechanical change that can be made in the recorder.

The slowest speed at which the spectrophotometer would be required to operate results in a scanning speed of 8 hr/μ. Spectrophotometer scanning speeds can be increased by factors of 2; and the recorder is designed to operate on 4 ranges, having a range of speed of a factor of 8. From the 8 hr trace for 1 μ mentioned above and the 40 cm length of record desired, it is clear that the paper will be moving at a rate of 5 cm/hr. For the Bristol recorder, the motor speed M is related to the paper speed P by the equation

$$M = 0.6675P(T/B) \text{ rpm},$$

where T is the number of teeth on the top change gear and B the number on the bottom change gear. If the values of paper speed of 5 cm/hr and a gear ratio $T/B = 4$ are inserted, the motor speed is 5.40 rpm. This is an average figure since the motor speed changes over the 2-μ range for which the instrument might be set. If the spectrophotometer were speeded up by a factor of 8 the motor would have to deliver 43.2 rpm; and since the motor should not be running at its top speed in order to provide proper follow-up servo action, a still higher motor speed would be desirable.

If the switch S_1 is closed there will be a permanent unbalance between E_2 and ground. The motor will run at top speed resulting in a linear wavelength presentation.

Logarithmic Recorder

The linear slidewire in the bridge circuit of the Bristol recorder has been disconnected and a 1000-Ω logarithmic potentiometer (C.I.C. Ser. D181) with a range of 1.2 decades has been geared to the potentiometer shaft. In addition a logarithmic radio-type potentiometer (Clarostat A47-75K-V) has been geared to the slidewire potentiometer to maintain constant servo loop gain.

Special attention must be given to the calibration of the density recorder. Three controls have been provided for this purpose: S_1, S_2, and R_1 (see Fig. 3). On "calibration" the signal from the network is sent directly into the recorder; on "zero" the signal from the network is in series with the spectrometer input; and in the "use" position the signal from the spectrometer is introduced directly into the recorder. From $D = 0.0$ to 1.0, we are switching between voltages differing by a factor of 10.

Recorder calibration is effected by adjusting R_1 for zero chart reading, with S_1 in the calibrate position and S_2 in the density 0 position. By switching S_2 to the density 1 position, the chart reading for $D = 1$ is established.

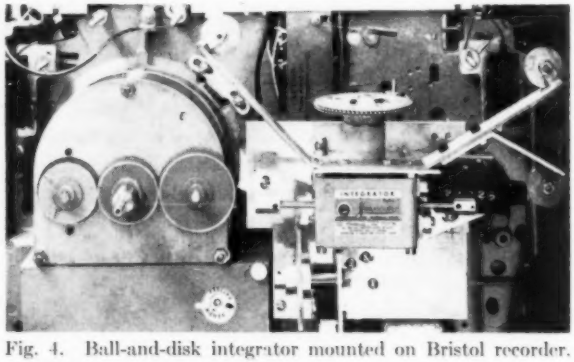
Fig. 4. Ball-and-disk integrator mounted on Bristol recorder.

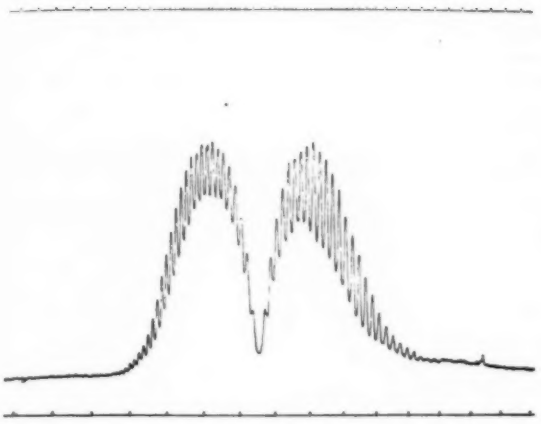

Fig. 5. Sample spectra of the CO fundamental taken at 19 atm in a 0.5 mm cell. The ordinate is in optical density units, while the abscissa is in wavenumber units. Integrator readouts are on the top. Wavelength markers from the spectrometer (0.05-μ intervals) are on the bottom. The markers range from 5.10 μ on the right to 4.35 μ on the left.

Absorption curves are generally recorded with S_1 in the zero and S_2 in the density 0 position. The spectrometer output is adjusted to provide an output of 0 V at $D = 0$ and to provide the necessary voltage to attain the established chart position for optical density 1. Alternatively, S_1 may be in the use position and the spectrometer output adjusted to provide 0 V at infinite density (100% absorption) and the proper voltage to attain a full-scale reading at optical density 0.

Integrator

In order to measure the area under the absorption curve, a ball-and-disk integrator has been incorporated into the recorder.

As shown in Fig. 4, the integrator is mounted on the main frame of the recorder by means of brackets. Coupling of the density axis is made through the use of fine (0.04) Nichrome wire wrapped around the pen drive shaft. Constant tension on the wire is accomplished by a return circuit having a spring. This arrangement solves the problem of the "linear cam" without the necessity of correction for cam-follower diameter and keeps the forces on the integrator slide along its axis only. The two gears shown at the right and left of the main shaft connect to the logarithmic slidewire and log gain control.

Since the wavenumber drive is not linear in time, it is necessary to use direct coupling between the disk and the paper drive. This coupling is made with bead chain as shown in Fig. 4. The counter at the right indicates the position of the slider of R_2 and thus assists in setting up the instrument. The friction coupling between the paper drive and R_2 is seen below the counter where the bead-chain coupling comes through from the paper-drive gearing.

A photograph of the pressure-broadened fundamental of CO recorded with this apparatus is shown in Fig. 5. The pip marks at the top are made from a switch that provides 1 pip for each 5 rev of the integrator shaft.

Discussion

The Borg micropot has a linearity of $\pm 0.1\%$ full scale, and this limits the ultimate accuracy of the wavenumber drive. An analysis of sample data was made for the 4 to 6-μ region. The average deviation of the wavenumber markers from a linear interpolation between end points was 1.29 cm^{-1}. Since the full range of the micropot represents 833 cm^{-1} the error corresponds to the linearity of the potentiometer.

The operating characteristics of the integrator were determined for the range $D = 0.00$ to $D = 0.70$. The average deviation was 1% of the maximum deflection. In covering this range 75% of the distance from the disk center was used. The results were in close agreement with the manufacturer's specifications of 0.5% of full scale. In this regard it should be noted that integrators are available with specified accuracies of 0.05% of full scale.

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photo D. L. MacAdam

Joseph Altman *Eastman Kodak* arrangements committee Program Chairman Rochester Section and W. R. J. Brown *United-Carr Fastener Corp.* 1956 Lomb Medalist. Dr. Altman is the co-author with the Past President of the Society of a Letter in this issue.

From the Editor

In the early days of this journal one of the measurements which the Editor spared from his metric converter was the specification of grating ruling, such as "15,000 lines/inch". Your Editor has seen these ruling engines, and they are elaborate monsters beyond normal comprehension, but we assumed that somewhere inside this mechanism a motor turned a worm-screw with, say, 32 threads per inch (a good American pitch) which with appropriate gear reductions produced exactly 15,000 strokes per inch. It seemed to us that it just would not be right to change this nice round number to "590.55 lines/mm". One evening last fall we visited Dave Richardson of Bausch & Lomb, one of the producers of such gratings, and asked him just how close such a ruling actually is to 15,000 lines per inch. "Oh", he said "it's really something like 15,240, so that it is just 600 lines/mm."

Similarly, most people who feel the diameter of the 200-inch telescope is sacred do not have any real feeling about just how close this value is to 200.0000 inches. Europeans variously refer to this telescope as the 5-meter or the 508-cm telescope. (Actually, since the secondary mirror obscures part of the primary it is more meaningful to describe the power of this telescope in terms of the effective area of the collector, or 1.7×10^8 cm^2.) Astronomers, by the way, surprised your Editor by having stronger feelings than most other groups about the sacredness of English units. A telescope aperture should be in *inches* and its focal length in *feet*. (Other dimensions, such as image sizes, slit-widths, etc., can nevertheless be expressed in cm, mm, or μ.) One is driven to suspect that somehow the Imperial Yard was originally found in the depths of the pyramids, from whence came the astronomers themselves. "How", one of them asked, "would one express a light-year in metric units? Or a parsec?" Far be it from us to disturb their reveries; they are pondering bigger things than most of us, and which of us by taking thought can add one cubit unto his stature?

It appears to be a common misconception in the nonmetric community that this metric system of arbitrarily defined and fabricated units is somehow going to transform the immutables of science into simple multiples of ten. This is not so: π remains an awkward number, as does Avogadro's number or the mechanical equivalent of heat, and we will continue to have both sidereal and mean solar years consisting of the same number of seconds (respectively) as before. The old "pint's a pound the world around" becomes less euphonious in liters and kilos, but is still just as true as it ever was (which wasn't much). In either system the measurement of time remains the same, and since the present system is already universally used there is little agitation for change. Every now and then one hears grumbling about the practice of calling midnight "twenty-four hundred hours", and occasionally we miss a plane because it departed at 9 a.m. when we thought it would be 9 p.m. but we appear to be stuck with this system and its merits or faults have nothing to do with our discussion of the metric system. We might note in passing that the definition of time is rather tricky and involves some necromancy: the second was redefined by the International Committee on Weights and Measures in 1956 as 1/31,556,925.-9747 of the tropical year 1900. (A tropical year is the interval between two consecutive returns of the sun to the vernal equinox.) If through some mischance our clocks should slow down or skip a beat, all that we need to do is go back to 1900 and recalibrate.

From time to time proposals have been made to decimalize time and angles. In 1856 one author evolved an elaborate plan in which the day had 10 hours of 100 minutes of 100 seconds and the right angle had 100 degrees similarly subdivided. He went on to propose other changes, such as ten months to the year. Augustus de Morgan, discussing this in his *Budget of Paradoxes* (1872), felt that "it was fortunate that there are ten commandments so there need neither be addition to, nor deduction from, the moral law. But the twelve apostles! Even rejecting Judas there is a whole apostle of difficulty."

When an author has been reluctant to change to metric units, we have conceded to his whim, allowing his units with the metric equivalent inserted parenthetically. One reader feels that this practice is an insult to the intelligence of a scientist, who should be able instantly to make this mental conversion. If this were indeed so we would have no problem at all: we would convert completely to metric and let those scientists who think in English bear the burden of conversion. Most of us know that an inch is 2.54 cm, that a km is about $^5/_8$ of a mile and a kg about 2.2 lb, but that is about as far as it goes without a table of conversion factors. How many joules in a Btu? How many cm^3/sec correspond to a ft^3/min? Don't feel insulted, we don't know either. What distinguishes a scientist from his fellow man is fundamentally his scientific education rather than his intelligence; we are not aware that the average scientist is any more intelligent than the average anybody else. We should regard these parenthetical conversions simply as a reminder that we are in a period of transition to a new and better system. When Great Britain and its American colonies finally adopted the Gregorian correction to the Julian calendar in 1752 (in which year 3 Sept., Old Style, was followed by 15 Sept., New Style), most people for several years added (N.S.) after every date, but the practice has rather fallen off of late, and most of us now who observe Washington's Birthday don't care whether it is 11 February (O.S.) or 22 February (N.S.), so long as it is a holiday. It is interesting to note that the lapse of time between the promulgation of the Gregorian calendar in 1582 and its adoption by the English in 1752 is just about the same as that since the formulation of the metric system in 1796. We are right on schedule.

JOHN N. HOWARD

photo Jacqueline

John Howard *AFCRL* (left), David Z. Robinson *Office of Science and Technology*, and T. K. McCubbin *Penn-State*, Editor, May 1962 Feature Editor, and Patents Panelist, respectively.

Helium Continuum Light Source for Photoelectric Scanning in the 600–1100 Å Region

R. E. Huffman, Y. Tanaka, and J. C. Larrabee

An intense Hopfield continuum having relatively stable average intensity with time, few superimposed emission lines, and low scattered light, has been obtained in the 600–1100 Å region from a helium gas discharge. A mild condensed gas discharge produces the continuum at an optimum pressure of about 40 mm Hg. The discharge circuit contains an external series spark gap, which is air blown and irradiated with a mercury lamp to improve its stability. After warm-up, the slow drift in intensity of the system over 4 hr is about 3%. Details of construction and operation are discussed, and initial results showing the use of this source to obtain absorption coefficients of gases by photoelectric scanning are presented.

The need for a continuum light source suitable for photoelectric study of absorption processes in the 600–1100 Å wavelength region has been apparent for a number of years. Although it will doubtless find application in other investigations, the source described here was developed for the study of absorption in gases by the photoelectric method. A number of earlier investigators have studied absorption processes in this wavelength region, using background light sources that emit many lines or bands rather than a continuum. For example, the hydrogen bands have been used by Watanabe[1] and his associates down to 840 Å. A high-voltage spark at low pressures has been used by many workers, including Weissler,[2] Vodar and Romand,[3] Curtis,[4] and their collaborators to a lower wavelength limit of about 150 Å. Although valuable information concerning the general shape of the continuum is obtained, it is impossible to study the actual shape of the absorption continua, which in the molecular gases are greatly complicated by superimposed absorption bands. Therefore, for the present investigation a continuum source is preferable to the more commonly used sources providing discrete emission lines.

Such a continuum source is the molecular helium continuum between, roughly, 600 and 1100 Å, which was discovered and studied by Hopfield[5] many years ago and which has found extensive application as a background light source for absorption spectroscopy using the photographic method. It is excited in a condensed discharge through a few mm Hg pressure of purified helium. More detailed studies of the excitation conditions and spectra produced have been made by Tanaka *et al.* During these investigations, continua were also produced in neon, argon, krypton, and xenon in the vacuum ultraviolet. In order to use the helium continuum for photoelectric scanning, however, the intensity and stability of the light source had to be improved. This paper describes a gas discharge having these improvements. An earlier study of spectroscopic observations of high-pressure helium discharges has been published.[7] The light source used in this earlier investigation was modeled after a different discharge tube, which also produces the helium continuum, recently described by Hinteregger[8] and his associates.

Other sources producing a continuum in this wavelength region have been reported. The Lyman-continuum flash tubes recently improved by Garton[9] and his associates emit a continuum typically extending beyond both the shorter and longer wavelength limits of the source used here. However, the flash-tube sources that have been described generally have low pulse repetition frequencies, which makes photoelectric scanning very tedious at best. There are generally numerous emission lines and bands superimposed on the continuum. In addition, it has recently been reported by Balloffet *et al.*[10] that a continuum extending to the soft x-ray region can be produced by a specially triggered spark discharge. Tomboulian and Hartman[11] have measured the continuum radiation from a synchrotron, which extends through the general region of interest discussed here into the soft x-ray region.

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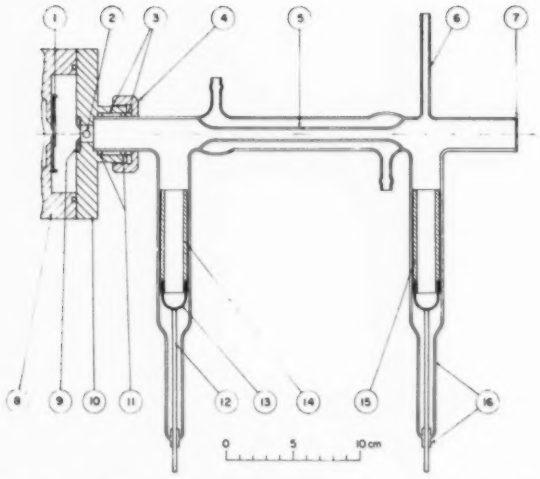

Fig. 1. Gas-discharge light source: (1) monochromator entrance slit, (2) source gas pressure gauge port, (3) O-ring spacers, (4) compression nut, (5) water-cooled capillary, (6) source gas entry tube, (7) quartz end window, (8) monochromator, (9) pre-slit, (10) source adapter plate, (11) silicone rubber O-rings, (12) tungsten rod, (13) tungsten yoke, (14) aluminum anode (grounded), (15) aluminum cathode (high potential), (16) quartz to tungsten graded seal.

Experimentation

The π-shaped quartz discharge tube used to produce the Hopfield helium continuum is shown in vertical cross section in Fig. 1, with the components identified by numbers in the caption. With the exception of the electrodes and the graded seals, the discharge tube is constructed entirely of quartz tubing, thus enabling higher energy dissipation. The discharge occurs between the 2 identical electrodes through an 8-mm i.d. water-cooled capillary. The cathode is operated at a high negative potential, and the anode is at ground potential. Each electrode assembly is composed of a tubular aluminum electrode (99.0% minimum aluminum content) supported by a tungsten wire yoke mechanically crimped to the electrode and fused to a 2-mm diam tungsten rod with a nickel bead. This tube has been operated for over 500 hr, although it is necessary to clean deposits from the electrode with sodium-hydroxide solution after each 125 hr of operation. Slit clogging by solid particles torn from the electrodes by the discharge, which was a problem with the light source used in the previous investigation,[7] has not been encountered here. Although this tube has proved to be very satisfactory, it is not known whether this design approaches the optimum size and shape.

The discharge tube is attached to the monochromator housing by an aluminum adapter plate and a compression-type double silicon O-ring seal providing mechanical support for the discharge tube. In operation, as shown in Fig. 1, purified helium flows into the discharge tube through an entry tube (6), then through the capillary (5) and pre-slit (9), and finally through the entrance optical slit (1), where it is almost entirely removed by the differential pumping system. It is necessary to purify the tank helium by passing it through charcoal traps cooled with liquid nitrogen. The helium pressure in the source is measured at port (2) by a Wallace and Tiernan mechanical absolute-pressure gauge. A quartz window (7) is glyptalled to the end of the discharge tube for visible spectroscopic observations.

The excitation circuit is shown in Fig. 2. The light output is produced by a series of rapidly occurring, mild, condensed discharges, with a typical repetition frequency range of 1–5 kc/sec. The capacitors used are of the small, high-voltage, cylindrical "cartwheel" type, developed for television receivers, rated at 20 kV 500 pF. Following the series of tests described below, 4 of these capacitors were connected in parallel between 2 copper sheets to form the energy storage bank, which therefore had a total capacitance of 0.002 μF. The connection wires to the discharge tube were made as short as possible, but no attempt was made to reduce the self-inductance of the discharge circuit to the absolute minimum. The other parameters, such as the average current and the charging voltage, will be discussed later.

In order to produce a strong continuum, it is necessary to use an external spark gap, as shown in Fig. 2. The gap is formed by two 6-mm diam tungsten rods separated by 2 mm. A blunt, rounded point is ground on each electrode, and the holder is designed to allow the electrodes to be accurately aligned. The gap is inherently unstable, however, and creates electrical noise. It is therefore necessary to stabilize the gap before suitable recorder traces were obtained. A jet of compressed air was passed between the electrodes at the highest pressure available in the building system (about 5 atm), and, in addition, the electrodes were irradiated

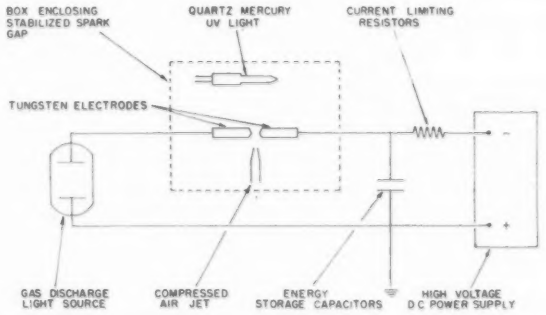

Fig. 2. Schematic diagram of discharge-tube electrical connections.

by a small quartz ultraviolet mercury lamp. It was found necessary to have both the compressed-air jet and the ultraviolet irradiation for maximum stability. The spark gap, compressed air nozzle, and mercury lamp are enclosed in an air-tight sheet-metal box containing glass-fiber acoustical padding around the walls. The box is connected to the fume hood by tubing in an attempt to remove ozone formed by the air spark gap. It has been found necessary to replace the spark-gap electrodes daily in order to keep the recorder photocurrent trace noise to a minimum.

The vacuum monochromator had 2 compact differential pumping stages attached to the monochromator side of the entrance optical slit shown in Fig. 1. The differential pumping system permits the discharge tube to be operated with high pressures of helium in a windowless manner, which is necessary in this wavelength region because of the lack of rugged window materials. Pressures of over 1 atm in the discharge tube can be maintained with about 1-μ Hg pressure in the monochromator chamber and a 20-μ wide entrance slit. However, as will be described more completely below, there is an optimum pressure for producing the Hopfield continuum with the present method of excitation. Although this optimum pressure has been found to be different for various discharge-tube designs, it has always been found at less than 100-mm Hg pressure, and in the present case there is a fairly sharp maximum at about 38-mm Hg. This circumstance makes it permissible to use less differential pumping, or, conversely, it allows a wider entrance slit to be used. Also, more pumping capacity is available to maintain an insignificant residual pressure of sample gas coming into the main chamber from the windowless absorption cell behind the exit slit. Throughout the work reported here, 100-μ entrance and exit slits were used, and at the optimum discharge pressure mentioned above, the residual pressure in the main chamber was about 1×10^{-5} mm Hg on a Veeco Bayard-Alpert gauge calibrated for air. In the present application, a low residual monochromator pressure is quite desirable; but if this is not the case the pumping requirements can be relaxed, since the Hopfield continuum will not be absorbed by higher pressures of helium in the monochromator chamber.

The radiation was dispersed with 2.218-m normal incidence monochromator manufactured by McPherson Instruments, equipped with a magnesium fluoride coated Bausch & Lomb replica grating having 1200 lines/mm. It was blazed at 1500 Å in the first order and produced spectra almost 2 orders of magnitude greater in intensity than similar gratings blazed at 3000 Å. Using 100-μ entrance and exit slits, the calculated bandwidth of radiation from the exit slit is about 0.5 Å, which is in agreement with the measured half-width of the impurity emission lines.

The dispersed radiation was detected in the conventional manner with a sodium salicylate fluorescent screen and a photomultiplier sensitive to this fluorescent radiation. The sodium salicylate is coated to the inside of a glass window which seals the rear end of an absorption cell located directly behind the exit slit. The end window of the photomultiplier is then placed close to the cell window. This arrangement has been found to give less photomultiplier noise than the alternate technique of coating the photomultiplier end window itself and sealing the cell around a photomultiplier tube body. A 14-stage EMI tube—either 9514B or 9514S—was used at typical operating potentials of 1300–1400 V. One of the various types of open multipliers might have been less sensitive to scattered light, but use of this technique was not possible because of interference of the multiplier operation by the higher sample pressures necessary to obtain gas absorption coefficients. Fortunately, as will be discussed in more detail later, the scattered light in the present case was quite small. The absorption cell contained ports for flowing in sample gas and for measuring the sample gas pressure.

In order to study gas absorption in the wavelength region below the LiF limit, the cell was attached to the monochromator exit slit directly, and no front window was used. The sample gas could leave the cell only through the exit slit, but the main chamber oil-diffusion pump had enough capacity that the main chamber pressure rose an insignificant amount. Since the exit slit moves slightly when scanning, it was deemed necessary to mount both the absorption cell and the photomultiplier on the exit slit holder and, therefore, inside the vacuum system. Gas line connections to the outside were made with flexible teflon tubing.

The photocurrent was measured with a Victoreen VTE-1 electrometer, using generally a time constant of 0.1 sec, and recorded on a Sargent Model SRL potentiometric recorder. Repetitive superimposed recorder scans over the same wavelength region were made convenient by placing a cam-operated relay on the wavelength counter drive. By this means the recorder could be started for each scan at the same fixed wavelength. Since the cam made one revolution in 5 Å, it was possible to start the recording within 5 Å of any chosen point throughout the spectrum.

Observations

General

The helium continuum trace using the most practical operating conditions found here is shown in Fig. 3, which is an ink tracing from the recorder chart. All of the pertinent operating conditions are listed in the caption. It can be seen that the continuum has 2 principal intensity maxima, at about 810 and 670 Å, respectively. This resembles the condensed discharge

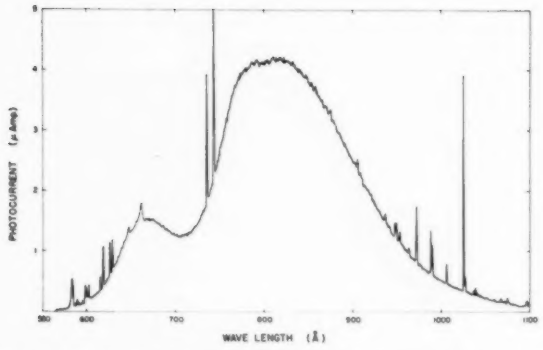

Fig. 3. Recorder scan of Hopfield helium continuum in 600–1100 Å region. Tracing from original chart. Source conditions: helium pressure 36 mm Hg, 9.5 kV, 90 mA, 0.002 μF, 50 kΩ charging resistors. Spark-gap distance 2 mm. Pulse repetition frequency varied between 4.5 and 5 kc/sec. Entrance and exit slits 100 μ, bandwidth 0.5 Å, scanning speed 50 Å/min. EMI 9514B photomultiplier operated at 1530 V, dark current 0.4 μA, sodium salicylate phosphor. Electrometer time constant 0.3 sec and chart speed 3.8 cm/min.

spectra of ref. 6. Although the detailed shape was changed somewhat by each grating, in using gratings where an appreciable intensity was observed the 2 principal maxima were always present when an external spark-gap trigger was in the circuit. In addition, helium bands, at about 662, 648, and 601 Å, and the self-absorbed 584 Å resonance line can be observed. Also observable in the figure are a few superimposed impurity emission lines. The most intense of these were always the neon resonance lines at 736 and 743 Å. In addition, a number of neon lines occur in the 584–630 Å region. The Lyman series of the hydrogen atom in the 900–1025 Å region has always been observed, but it decreases in intensity with time. The other lines in the 900–1100 Å region are principally due to OI and CI. The impurity lines provide convenient wavelength standards, and by using these standards it has been found that the monochromator scanning rate is constant to within 1 part per thousand over the 600–1100 Å range.

Absolute Intensity Measurements

The absolute intensity of the radiation from the exit slit was measured in the following manner.* A LiF-windowed, NO-filled ionization cell calibrated for hydrogen Lyman α radiation (1215.7 Å) was placed beside the gas-absorption cell on the exit-slit holder of the monochromator so that it would intercept the radiation passing through a separate exit slit on the focal curve. The ionization cell had 22.5 V impressed across the collection electrodes, and the current produced by the radiation was measured with a Keithley Model 415 electrometer. The measurement was made using the conditions that produced the continuum as shown in Fig. 3. Initially, the monochromator scanned the ionization cell over the position of H Lyman α, and the current maximum was read. Then, the same wavelength region was allowed to scan across the photomultiplier in the absorption cell. After scanning carefully across the line at 1215.7 Å, the helium continuum in the 600–1100 Å range was scanned more rapidly. In this manner, both the ionization-cell current and the helium continuum photomultiplier intensity maximum could be compared to the H Lyman α photomultiplier intensity under identical conditions of light-source operation. Assuming sodium salicylate to be a linear photon detector between 1215.7 Å and about 810 Å, the peak of the continuum, the number of photons per sec through the exit slit can easily be calculated. At about 810 Å, this procedure gives an average value of 2.5×10^7 photon per sec through the exit slit and a flux of 5.0×10^9 photon per cm^2 per sec. Using this value to calibrate Fig. 3, the flux from any region of the continuum can be obtained. The relative quantum efficiency of sodium salicylate[12] has been found to be linear with wavelength at a number of wavelengths down to about 850 Å. One additional measurement was done at 584 Å, which gave a value about 15% lower than the linear region. Therefore, the assumption that the relative fluorescent efficiency is linear is probably satisfactory for the present purposes, although further measurements at lower wavelengths would be desirable.

Stability and Scattered Light

The random noise present on the recorder traces cannot be well evaluated from Fig. 3 since the tracing

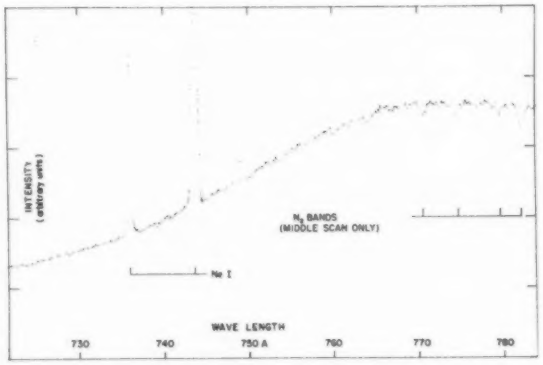

Fig. 4. Repetitive photoelectric scanning charts illustrating stability of light output. Conditions approximately same as Fig. 3, except 0.1-sec time constant. Three superimposed traces. Monochromator chamber had 3×10^{-5} mm Hg nitrogen during second scan. Total elapsed time for experiment, 90 min. Recorder chart photograph.

* The participation of J. A. R. Samson in these intensity measurements is gratefully acknowledged. The ionization cell was constructed and calibrated by K. Watanabe and J. A. R. Samson at Geophysics Corporation of America.

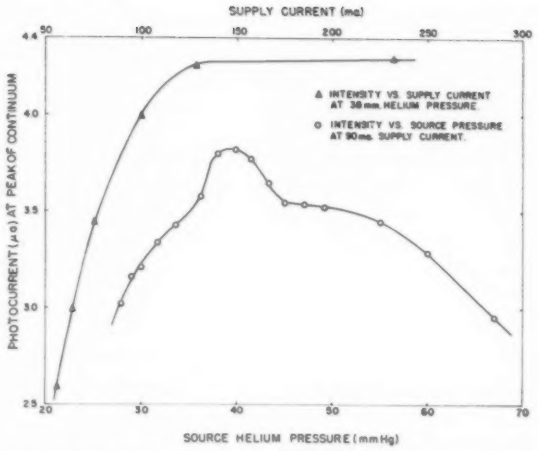

Fig. 5. Continuum intensity as function of supply current and source pressure. Other conditions as in Fig. 3.

distorts the noise to some extent. A better feeling for the amount of noise present can be obtained from Fig. 4, which also illustrates the stability and reproducibility, and from Fig. 7, which will be described later in discussing absorption measurements. The typical noise level was 3–4% of the mean intensity at all usable intensity levels.

Figure 4 illustrates the stability and reproducibility of the light intensity on three successive superimposed traces. The actual recorder trace has been photographed in such a way that the grid lines do not appear. The total elapsed time during this determination was about 90 min, and it can be observed that the long-term drift is less than the random noise. During the second scan, a small amount of nitrogen was allowed to flow through the main chamber of the monochromator. This amount corresponded to the residual pressure of nitrogen typically present during an absorption experiment. It can be observed that only the most intense nitrogen absorption bands are present and that the source-light intensity is not affected. Therefore, the influence of residual sample gas in the main chamber is small.

The scattered-light level was found by placing a lithium fluoride window over the sodium salicylate fluorescent coating to absorb all wavelengths below about 1050 Å. The total scattered-light level was found to be less than 2% of the total intensity over most of the wavelength region of the continuum. One reason for this low scattered-light level is the small amount of radiation in the 1100–3000 Å region, which consists of only a few impurity lines and one helium atomic emission series. This is in contrast to the results with a discharge tube previously used,[7] which had an intense continuum in this region and a large amount of scattered light in the Hopfield continuum region. With a windowless monochromator such as this, there is also the possibility that spurious radiation of wavelengths below 500 Å may be detected, either as higher orders of lower wavelength radiation or as scattered light. This is not a problem with the high-pressure helium discharge, however, because this radiation would be absorbed in the discharge by the helium ionization continuum extending to wavelengths below 510 Å.

Optimum Conditions

The procedure used in determining the best operating conditions is described below. Ideally, this would involve study of the continuum intensity as a function of the significant variables within the limits imposed by available power supplies and associated equipment. Unfortunately, vacuum ultraviolet producing discharges are not well understood, and similar apparatus may yield considerably different results. Also, the number of variables is large, including, of course, the dimensions of the light source, which are not easily varied. Nevertheless, an attempt has been made to optimize the conditions, and the procedure is described for illustrative purposes rather than to give definitive parameters for general application.

With the discharge-tube design fixed as shown in Fig. 1, the light intensity variables included gas pressure, observed average power supply current, pulse repetition frequency (PRF), capacitance, spark-gap distance, charging voltage, and total power supplied to the source. Since the voltage at which the discharge tube fires is determined by the spark-gap setting, which was optimized in preliminary experiments and has remained constant here, the observed average supply current is a measure of the power used by the source. Therefore, the last three variables mentioned above do not need to be considered.

The previous study of discharge excitation conditions indicated that an optimum pressure should exist for the excitation of the Hopfield helium continuum. This optimum pressure was located with the present discharge tube and excitation circuit at approximately 38 mm Hg. The best value of capacitance was found by measuring the intensity of the peak of the continuum using different values of capacitance at the approximate optimum pressure. The PRF was obtained by displaying the signal from a small antenna near the discharge tube on an oscilloscope, and the results were plotted for equal PRF. Above a PRF of about 5 kc/sec the "pick-up" noise on the recorder became excessively high. Generally, the highest PRF and the smallest capacitance usable gave the most intense continuum. At equal PRF the continuum was more intense with 0.004 or 0.002 μF rather than higher values. Since less current was required with 0.002 μF and the intensities were about equal, this value was adopted.

Using the optimum pressure of 38 mm Hg and

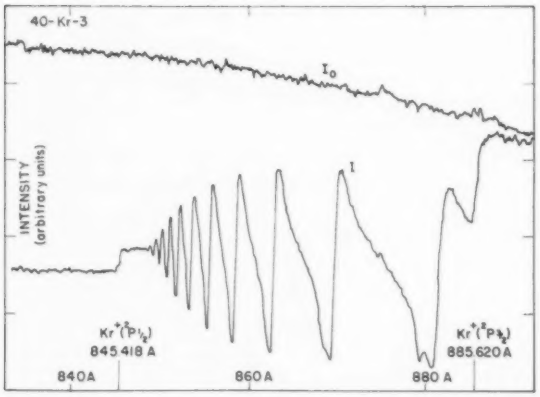

Fig. 6. Krypton absorption record showing autoionized lines. I_0 is with no gas in the cell, I is with krypton flowing through the cell. Tracing of chart record. Krypton pressure about 70μ Hg and cell length 10 cm.

capacitance of 0.002 μF, the continuum intensity as a function of indicated meter current was studied. The results, which are given in Fig. 5, indicate that a relatively constant intensity is reached at about 125 mA; however, the higher currents lead to rapid deterioration of the spark-gap electrodes, resulting in shorter operating periods before excessive noise makes it necessary to replace the spark gaps. A compromise value of 90 mA was used, allowing a spark-gap lifetime of over 8 hr with about 90% of the maximum intensity. The upper current value of about 230 mA in Fig. 5 is roughly the largest current usable with this source.

Also shown in Fig. 5 is the variation of continuum intensity with pressure at 90-mA supply current and with 0.002-μF capacitance. There is a fairly sharp intensity maximum at the optimum pressure of 38–40 mm Hg. Therefore, the pressure was generally kept within the 35–38 mm range, where the continuum intensity is somewhat less affected by pressure fluctuations. This determination completed the optimization of the variables, and the observed best values are given in the caption for Fig. 3.

Application to Absorption Studies

The Hopfield continuum recorder traces obtained with the present system were judged to have adequate intensity and stability for repetitive photoelectric scanning. Although much room for improvement remains, it is possible to measure absorption coefficients with the moderate resolution of 0.5 Å. Examples of the application of this source to the measurement of gaseous absorption coefficients of krypton and hydrogen are shown in Fig. 6 and Fig. 7, respectively. These are average traces; in some other cases the noise was considerably less than shown. Figure 6 illustrates the broad autoionized lines discovered by Beutler[13] between the $^2P_{1/2}$ and $^2P_{3/2}$ ionization thresholds in krypton. Present resolution makes it possible to obtain the oscillator strength of these lines. These measurements are in progress and will be reported elsewhere in the near future.

Figure 7 is a portion of the absorption spectrum of H_2 covering a wider region than the previous figure. In addition to the photoionization continuum, which extends to shorter wavelengths, with almost constant intensity, from the indicated ionization threshold ($I.P$ = 15.426 eV, 803.67 Å),[14] a dissociation continuum is also observable in the figure. The latter begins at about 845 Å (14.68 eV)[15] corresponding to the energy of the dissociation limit, $1s^2S + 2p^2P$, and extends toward the shorter wavelengths, where it is superimposed on the ionization continuum. The prominent progression of the absorption bands in the figure is composed of D–X and B''–X systems as indicated in the figure. The sharp intensity rise at $V' = 3$ in the D–X bands has been attributed to the predissociation occurring at this level.[16] The spectrum appears rather complicated in the region shorter than the wavelength corresponding to the ionization potential. This is probably due to the appearance of additional bands belonging to other systems, and, also, some of the bands may be affected by autoionization. The measurements are in progress, and detailed information will be reported elsewhere in the near future.

These studies are important not only because the processes, such as photoionization and preionization, are not well understood but also because these processes maintain the ionospheric layers of the upper atmosphere. Therefore, the values of the total absorption and photoionization cross sections are vital in developing an understanding of the upper atmosphere. In the wavelength region from 600 to 1100 Å, all of the primary atmospheric constituents have photoionization thresholds and intense ionization continua.

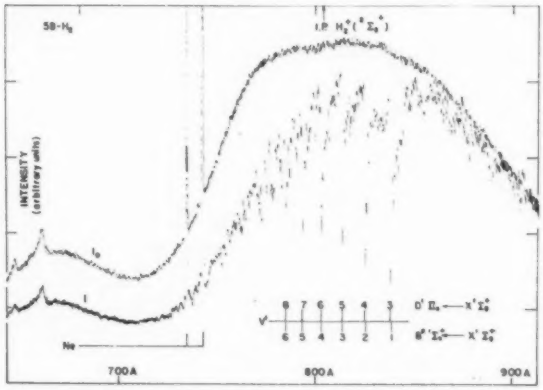

Fig. 7. Hydrogen absorption scan in the 650–900 Å region. Recorder chart photograph. Noise somewhat larger than typical. Hydrogen pressure about 0.32 mm Hg and cell length 10 cm.

It is planned to continue improving the helium continuum light source by replacing the spark-gap trigger with a thyratron trigger and by studying the light output per flash. In addition, new discharge-tube designs and materials will be tried in an attempt to obtain sources that will dissipate higher energies. Nevertheless, it is felt that the present source is a distinct improvement and should find application to problems requiring a continuum source in the vacuum ultraviolet.

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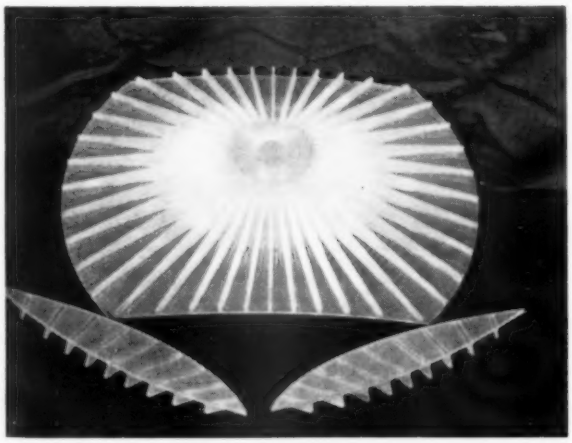
Applied Optics — Optical Activities in Industry

reported by FRANK COOKE, 66 Summer Street, North Brookfield, Mass.
Mr. Cooke welcomes news and comments for this column which should be sent to him at the above address



Back of "ground from the solid" lightweight mirror. Two smaller pieces were cut off after polish. The optical figure does not appreciably change providing the material has been properly annealed. Spherical accuracy of 1/4 wave was achieved. Optical surface was polished after ribs were cut.

Problem: to make a lightweight mirror without cementing or fusing.

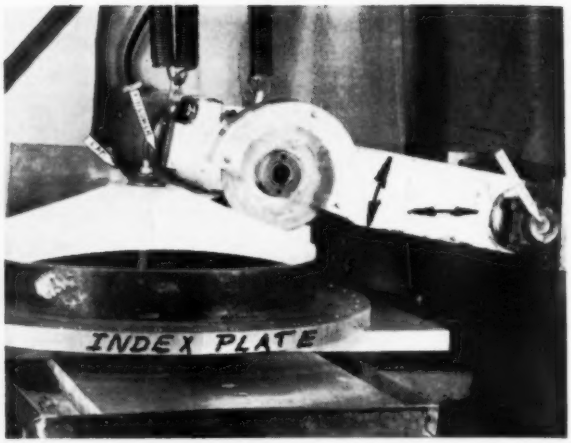
Considerable trouble had been experienced with assembled mirrors because, under vibration test or temperature cycle, they either came apart or lost their optical figure.

A block of well-annealed pyrex weighing 50 lb (22.7 kg) was ground to the illustrated configuration weighing 7 lb (3.2 kg) and polished to a spherical accuracy of 1/4 wave. Upon heat cycling and vibration testing no change was observed. The mirror could be made lighter by maybe 50%. Grinding from the solid is expensive and we suspect if many were needed the shape could be molded much cheaper.

additional figures overleaf

The figures illustrate a solution to the problem described on the previous page.

Bent and annealed pyrex blank in place on large sphere generator. The back convex surface is shown being ground. The concave surface is generated in a like manner, but, of course, the work is positioned under the right-hand edge of the diamond wheel.



Showing the machine used in grinding away the material leaving 40 ribs. Note the plate supporting the mirror with its 40 indexing holes. The motorized spindle with its diamond wheel is caused to rise and fall in an appropriate manner by the cam. The follower is the same diameter as the wheel. The cam is so shaped and adjusted that the cutting wheel maintains an even distance from the mirrors concave surface, in this case, 4 mm. Time to grind from edge to center stop approximately $\frac{1}{4}$ h. Width of diamond face is 4 mm. Its cutting corners are rounded so as to prevent sharp corners. Note the 3 springs pulling upward thereby removing excess weight. In case the diamond wheel is asked by excess feed to remove stock too fast, the resulting pressure at point of cutting contact will cause the arm to move upward.

The diamond edging wheel is fed straight down. The blank is rotated and is held on the chuck by use of vacuum. Diameter and roundness is held to 0.01 mm. This technique might be very useful for those who have large vertical spindle surface grinders.

Closer view of diamond wheel grinding material away between webs. Note single arrow showing contact between the follower and cam. The rise and fall of the motor grinding assembly is controlled by this cam.

July Issue Features Atomic Spectroscopy

A Multicolor Photoelectric Photometer for Artificial Satellite Observations

James G. Moore and Shelden D. Elliott, Jr.

A photoelectric photometer has been constructed that permits simultaneous and continuous measurement in three wavelength regions of the reflected solar radiation from artificial satellites. The instrument is fitted for manual tracking in altitude and azimuth coordinates, and is equipped with a one-meter catadioptric objective of 27-cm aperture. Light from an object in the field of view is dispersed into a spectrum by a 600 lines/mm diffraction grating, and the desired wavelength regions are isolated by means of narrow-band interference filters. A separate photomultiplier tube is used to measure the flux in each color. At present, the system is equipped with photomultiplier-filter combinations centered near 4750, 6015, and 7020 Å; observations at these wavelengths as the satellite passes into the earth's shadow permit determination of the variation with altitude of the density and ozone content of the atmosphere. Satisfactory records have been obtained during several passes of the balloon satellite, Echo I, and are currently being analyzed.

I. Introduction

Photometric observations of artificial earth satellites can provide detailed information on the earth's upper atmosphere. Venkateswaran, Moore, and Krueger[1] have demonstrated that simultaneous measurements at two or more selected wavelengths of the reflected solar radiation from satellites entering and leaving the earth's shadow can be used to determine the vertical distribution of various atmospheric constituents. From observations in two wavelength regions made during several passes of the balloon satellite, Echo I, these authors were able to determine the distribution with altitude of atmospheric ozone. These two-color observations were carried out using two photoelectric photometers of the type employed at the U.S. Naval Ordnance Test Station (NOTS) for night airglow research,[2] mounted in "piggy-back" fashion on a standard range tracking cinetheodolite.

Measurements at three or more suitably chosen wavelengths would be of even greater value. Thus, from similar measurements at 4750, 6010, and 7020 Å, at the peak and to either side of the Chappuis absorption band of ozone, it should be possible to determine both the vertical distribution of ozone and the variation of atmospheric density with height. With the addition of a third photometer, however, the previous arrangement was found to become excessively unwieldy. Such a system is, moreover, highly inefficient, since only one-third of the combined aperture of the photometer objectives is utilized in collecting light of a given color. It was decided, therefore, to construct a new instrument specifically for multicolor satellite photometry, with a single, large objective and a self-contained tracking mechanism.

II. Photometer Design and Construction

The acquisition of a surplus Askania-Werke KTh-40 cine-theodolite, fitted with a special one-meter T/5.6 catadioptric objective of 27-cm aperture, made the construction of such a photometer feasible. The theodolite incorporates a precise altitude-azimuth manual tracking system having fast and slow drives in both coordinates with provisions for attachment of a guiding telescope, while the camera body, stripped of its former contents, provides a light-tight housing for the optical system and the detectors.

The requirements on the system were that it be capable of simultaneous and continuous measurement of the flux from an external point source in three separate wavelength regions, and that the detector response for each color be constant over the finite field of view required for manual tracking. The low light levels and rapid fluctuations to be investigated dictated the use of photomultiplier tubes as detectors, necessitating a substantial physical separation of the three colors under

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study. A beam-splitting arrangement was initially considered, but was subsequently discarded in favor of a system combining a diffraction grating with a long, folded light path to give the required linear dispersion, and narrow-band interference filters to isolate the individual colors. A diagram of the optical system is presented in Fig. 1; a photograph of the completed instrument, partially disassembled to expose its interior construction, is shown in Fig. 2.

A circular field stop, 4.8 mm in diameter, is centered in the focal plane of the objective. This aperture provides an angular field of view of 16.5 min of arc, which has been found to be about the minimum size consistent with satisfactory tracking. Light from an external point source imaged within the field stop is intercepted by an achromatic doublet lens L_1 of 90-mm focal length and emerges as a collimated beam 24 mm in diameter. This beam falls, at a 30° angle of incidence, onto a 600 lines/mm Bausch & Lomb plane replica reflection grating, having a ruled area 52 mm square and blazed for 5000 Å in the first order at normal incidence. (At 30° incidence, the effective blaze wavelength is shifted to approximately 3900 Å, substantially reducing the efficiency of the grating in the spectral region under study. The present grating is to be replaced by a similar one blazed for 7500 Å at normal incidence, or about 5500 Å at 30°, giving enhanced efficiency over the range 2750–8250 Å and substantially improving the sensitivity of the system, particularly at longer wavelengths.) The first order spectrum leaves the grating in a direction approximately normal to that of the incident beam, and passes through a single-element positive lens L_2 of 293-mm focal length situated in the plane occupied by the image of the objective formed by L_1.

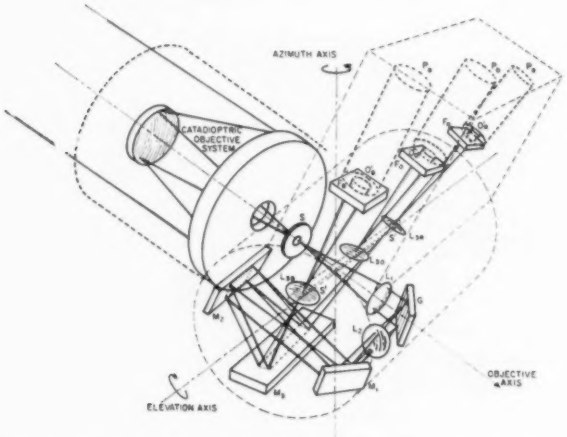

Fig. 1. Diagram of photometer optical system. L_1, L_2, L_3—lenses; M_1, M_2, M_3—front-surface mirrors; G—diffraction grating; S—field stop; S′, S′—field stop images (spectrum); F_B, F_O, F_R—blue, orange, and red filters; O_B O_R—monochromatic images of objective; P_B, P_R—photomultiplier tubes. (Official United States Navy photograph.)

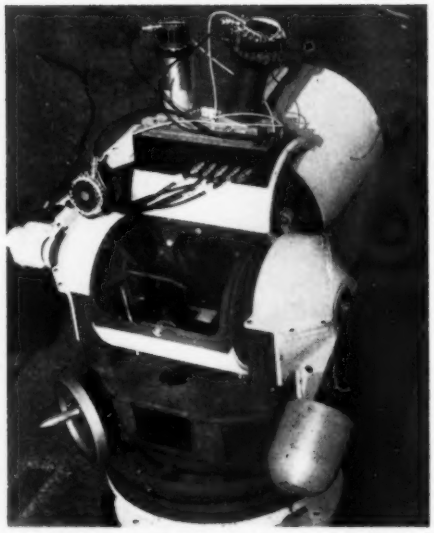

Fig. 2. Interior arrangement of photometer. The phototube cover has been removed and the central tube dismounted to show the orange filter in place in its recess. (Official United States Navy photograph.)

The spectrally dispersed beam then undergoes three reflections from the front-surface mirrors M_1, M_2, and M_3, and emerges from the last mirror in an upward direction, fanned out in a plane normal to the axis of the objective. A spectrum lying parallel to the elevation axis of the instrument is formed a short distance beyond M_3. This spectrum consists of a series of overlapping monochromatic images of the field stop, brought to a focus by L_2.

Three singlet field lenses L_{3B}, L_{3O}, and L_{3R}, each of 115-mm focal length, are mounted along this spectrum, centered at points corresponding to the three wavelength regions of interest, and the light passing through these lenses emerges through a slot on the top of the camera body to form a series of secondary images of the objective a short distance above the housing. A track straddling this exit slot, parallel to the elevation axis, carries a set of three blocks, in the recesses of which are mounted 5 cm × 5 cm narrow-band interference filters. The characteristics of these filters, as measured at NOTS with the aid of a Cary-14 monochromator, are listed in Table I. While the present filters are free of sidebands, this is not an essential requirement because of the physical dispersion produced by the grating.

Table I. Parameters of the Narrow-Band Interence Filters Used in the Photometer

Filter	λ_{max} (Å)	T_{max}	$\Delta\lambda(T_{max}/2)$ (Å)
Blue	4748	0.92	37
Orange	6009	0.70	38
Red	7016	0.69	38

The three colors defined by the filters will be referred to hereafter as "blue," "orange," and "red," respectively. The blocks are positioned along the track in such a way that the central rays in each color pass normally through the centers of the filters. The extreme rays in each color are incident upon the filter at angles not exceeding 5°, and the wavelength shifts thus introduced are negligible. Three "monochromatic" images of the objective approximately 15 mm in diameter are thus selected from the short spectra formed by the three field lenses; these images lie parallel to and a few millimeters above the upper surfaces of the filters.

Photomultiplier tubes encased in light-excluding sleeves are fitted into the filter blocks, with their faces in contact with the filters. An EMI 9514B, 13-stage photomultiplier having an S-11 photocathode response is used in conjunction with the blue filter; RCA 7265 14-stage photomultipliers with S-20 response are used with the red and orange filters. These tubes are end-on types, with photocathodes approximately 44 mm in diameter. The phototube sleeves are closed at their upper ends with caps carrying the tube bases and the dynode resistor networks. The high-voltage and signal leads are carried out to terminals on the track base. A light-tight sheet metal box houses the track and filter-phototube assemblies. The general arrangement of these components can be seen readily in Fig. 2, where the curved plate carrying the track has been lifted from the camera body, the phototube cover removed, and the central tube dismounted to show the orange filter in its recess.

The optical path from the grating to the photomultiplier cathodes is approximately 52 cm for the blue rays, and somewhat longer for the other colors. With the optical components so adjusted that light of approximately 6000 Å emerges near the center of the track, a total range of 4500–7200 Å is accessible along its length. The linear dispersion along the track has a mean value of 15 Å/mm. The physical size of the filter-phototube assemblies limits the minimum separation to 6 cm, or about 900 Å. With more compact tubes and filters the separation may be reduced to about 500 Å, this latter limit being imposed by the finite size (15–20 mm) of the monochromatic images of the aperture at the field lenses. The over-all wavelength region covered at the track may be shifted by rotating M_1, while changes in the individual color combinations may be accomplished by the installation of appropriate filters and phototubes, with corresponding adjustment of the positions of the filter blocks and field lenses.

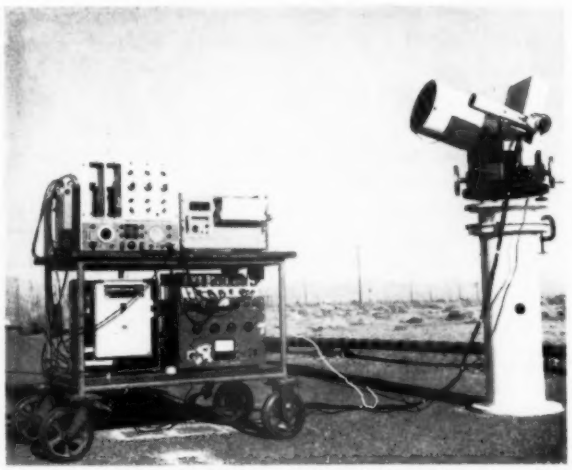

Fig. 3. Completed photometer installed on its pier. The phototube power supplies and the recording and monitoring system are carried on the cart to the left. (Official United States Navy photograph.)

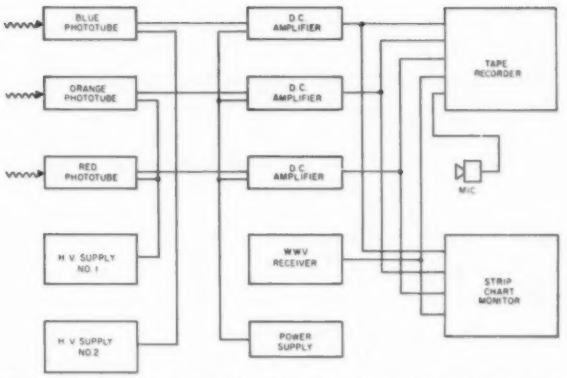

Fig. 4. Block diagram showing the electronic and recording components of the system. (Official United States Navy photograph.)

The spectral response of the assembled photometer was investigated with the aid of the Cary monochromator and, as given in Table I, was found to be essentially that of the filters themselves. Neither peak wavelengths nor bandwidths were found to be appreciably altered.

The uniformity of response over the aperture was determined by allowing stars to trail through the field of view in various directions while monitoring the output signals. The response was uniform to within a few percent across the field. With careful tracking, the satellite is held near the center of the field for the major part of the time, and the slight fluctuations due to mistracking are random in character and do not seriously affect the results obtained.

III. Operation

The assembled photometer is shown on its pier in Fig. 3, together with the cart carrying the phototube power supplies and the recording and monitoring system. The tracking telescope mounted on the near end of the elevation axle is collimated with the photometer objective, and is provided with an illuminated reticle on which the field of view of the photometer is indi-

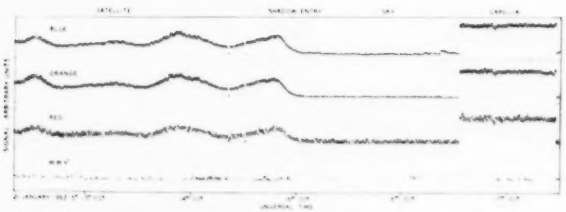

Fig. 5. Portion of chart record showing entry of Echo I into the earth's shadow about 0515 UT, January 21, 1962. From top to bottom, the traces represent the signals from the blue, orange, and red photometers and from the WWV receiver. The time is indicated at one-minute intervals on the lower margin. The constant signal from the star Cappella appears at the right on the top three traces. (Official United States Navy photograph.)

cated. Tracking is accomplished by means of the two handwheels visible on either side of the theodolite base.

A block diagram of the recording and monitoring system is presented in Fig. 4. The blue (EMI) phototube is operated at a cathode potential of −1500 to −1600 V, while the orange and red (RCA) tubes are operated at −2000 to −2200 V. The signals from the three phototubes are applied to a set of dc amplifiers, originally designed for the night-sky program, whose input resistors serve as load resistors for the tubes.[2] The load resistors may be changed to vary the sensitivity of the system, and the amplifiers may be biased, if necessary, to offset high dark current and sky background levels.

The amplifier output signals are applied to three channels of a seven-channel magnetic tape recorder, and are monitored on the first three channels of a Sanborn four-channel chart recorder. Time reference pulses at one-second intervals, obtained from a WWV receiver, are applied to a fourth channel on each instrument, while a microphone is connected to a fifth channel on the tape recorder for voice records.

The system is operated in the following manner during a typical pass of Echo I. From the Moonwatch predictions available locally, a pass is selected during which the satellite will enter the earth's shadow at a substantial elevation (at least 30°) above the horizon. Shortly before the pass, the system is turned on, and the phototube voltages, amplifier gains, and, if necessary, bias levels, are adjusted to give suitable deflections on the tape and chart records (the star Capella, which is near the zenith on winter evenings, is especially convenient for this purpose, being comparable in color and magnitude to Echo I). As the satellite appears above the horizon, the chart recorder is turned on, and the operator brings the satellite image to the center of the tracking telescope reticle. As the satellite is tracked across the sky, final adjustments are made on the basis of the monitor chart record, and reference points on the time trace are identified. Two or three minutes before the predicted eclipse of the satellite, the tape recorder is switched on, and a record is obtained of the decaying flux in each color from the satellite as it passes into the earth's shadow. The last portion of the satellite's path is rescanned to establish the local sky background level, and, finally, the photometer is directed at a bright star near the zenith to provide reference signals of known density.

A portion of the chart record obtained during the evening of January 20, 1962 (January 21, Universal Time) is presented in Fig. 5. From top to bottom, the traces represent the signals from the blue, orange, and red photometers, and from the WWV receiver. The early (left) portions of the traces show characteristic fluctuations in the brightness of the satellite due to irregularities in its surface; the short negative deflections are due to mistracking. Shadow entry begins approximately ten seconds before the 0515 UT mark, and by twenty seconds later, the satellite has disappeared. The subsequent portion of the trace represents the sky background, followed by an observation on Capella.

The tape record is subsequently played back into an analog-to-digital converter, background levels are subtracted, and intensity ratios among the three colors are derived as a function of time during the shadow entry period, from which the desired altitude distributions are computed.[1,3] The results obtained from the several sets of three-color records obtained to date will be reported in a subsequent paper. Preliminary analysis indicates, however, that the new system is capable of providing the desired information.

IV. Discussion

In general, the performance of the three-color photometer has been highly satisfactory. The manual tracking system is of adequate precision. The grating-interference filter combination in the optical train permits a degree of spectral resolution to be achieved that is limited only by the filter bandwidth and the sensitivity of the phototubes, despite the finite entrance and exit apertures of the system. The ready adaptability of the instrument to other color combinations over a wide wavelength range will permit a variety of observations to be undertaken.

The principal deficiency of the photometer in its present form is its relatively low sensitivity at the longer wavelengths. To a certain extent, this is an inherent problem in photoelectric photometry; the quantum efficiency of the S-20 cathode (the most sensitive currently available in this region) is down at 7020 Å to 10% of its peak value in the blue. The chief difficulty, however, lies in the low efficiency of the present diffraction grating, as noted above. The contemplated replacement of this grating with one better suited to the geometry of the optical system should yield a substantial improvement in the over-all performance of the photometer.

The three-color instrument may also be employed profitably for other purposes. The use of a common objective facilitates the study of color effects in stellar scintillation (the rapid fluctuation in apparent brightness of astronomical objects, due to inhomogeneities in the atmosphere), and preliminary observations of this phenomenon have been made for evaluation. The ability of the observer to follow a rapidly moving satellite from horizon to horizon over a period of a few minutes with this instrument, and to record simultaneously its apparent brightness at several wavelengths, should make it useful for the study of atmospheric extinction, avoiding the difficulties with long-term variations imposed by the much slower passage of stars across the sky. Simultaneous multicolor photometry of the brighter stars and planets also can be performed.

Although originally intended for observation of essentially point sources, the photometer may also be used to study extended bodies (the present field of view of 16.5 min of arc is, however, the maximum that can be obtained without major redesign of the optical system). While the sensitivity of the system is probably too low for the detection of night-sky radiation or zodiacal light, it should suffice for photometry of bright comets and aurorae. Simultaneous multicolor observations of portions of the Moon's surface during lunar eclipses also will be feasible and should be of considerable value.

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2. P. Saint-Amand, Ann. géophys. **11** (4), 435–448 (1955).
3. James G. Moore and S. V. Venkateswaran (to be published).

International Commission for Optics

CONFERENCE ON PHOTOGRAPHIC AND SPECTROSCOPIC OPTICS

Tokyo and Kyoto 1–8 September 1964

arranged by

SCIENCE COUNCIL OF JAPAN and JAPANESE SOCIETY OF APPLIED PHYSICS

A Conference on Photographic and Spectroscopic Optics, arranged on an international level by the Science Council of Japan and the Japanese Society of Applied Physics under the auspices of the International Commission for Optics, will be held in Tokyo and Kyoto, Japan, 1–8 September 1964. The Conference will be composed of some 10 sessions, and each session will include one or two invited papers (30–40 min presentation time) and some contributed papers (15 min each). The subjects to be dealt with at the Conference will be:

Design and Evaluation of Photographic and Spectroscopic Optical Systems
Recent Instrumentation in the Far Infrared and the Extreme Ultraviolet
Optical Materials for Use in Photographic and Spectroscopic Optics

Offers of papers should be made no later than 31 January 1964, by sending an abstract to the Organizing Committee. This abstract must be adequate for the Committee to decide on the suitability of the paper: the scope of the paper should be indicated, and principal new results included. The working languages of the Conference will be English, French, and German. However, in view of the fact that English will be the only language comprehensible to the majority of participants, speakers are strongly recommended to read their papers in English.

Visits to research institutes, universities, and optical companies are being planned. More detailed information will be circulated in due course.

All inquiries concerning the Conference should be addressed to: Prof. H. Kubota, Secretary, Organizing Committee, ICO-Tokyo & Kyoto, Science Council of Japan, Ueno Park, Tokyo. For planning purposes the Japanese Committee is very eager to estimate the number of people who will come. if you are interested in this meeting please write immediately to Prof. Kudota for further information.

The Publications of W. W. Coblentz on Infrared Spectroscopy

The principal work of the late W. W. Coblentz on infrared spectroscopy originally appeared in three Publications of the Carnegie Institution of Washington. Publication No. 35, issued in 1905, dealt with his investigations at Cornell University of the infrared absorption spectra of some 135 organic compounds, with shorter supplementary sections on transmission and reflection spectra. Publication No. 65 (1906) and Publication No. 97 (1908) are concerned with later work on the transmission and reflection spectra of minerals and other inorganic compounds carried out at the U.S. Bureau of Standards.

These classical investigations form the basis of most modern work on analytical infrared spectroscopy. The journals have long been out of print, but, with the kind permission of the Carnegie Institution, they have recently been reprinted in a single volume under the joint sponsorship of the Coblentz Society and the Perkin-Elmer Corporation.

All concerned with modern applications of infrared spectroscopy to problems of chemical structure and analysis should be conversant with this early work, which provides the basis for much of the modern technique. To maintain a properly balanced outlook on the subject, this volume should accompany the standard modern texts on the library shelf of the spectroscopy laboratory.

A limited number of copies of the first reprinting are still available at $3.50 per copy on application to Dr. H. B. Kessler, The Secretary, c/o The Perkin-Elmer Corporation, Norwalk, Connecticut.

OPTICS PEOPLE

A. Chapanis and Aleeza C. Beare *Johns Hopkins*, who gave a paper during the OSA Rochester Meeting last year.

R. S. Hunter *Hunter Associates*, a member of this journal's Patents Panel, and James De Palma *Eastman Kodak* during the OSA Rochester Meeting last October.

Erik Ingelstam *Stockholm*, retiring President, and P. Mollet *Belgium*, Vice President, of the International Commission for Optics, measure it.

W. F. Swann *Eastman Kodak* and Hilda Kingslake, Chairman of the Program Committee for last year's OSA Rochester Meeting.

Max Herzberger *Eastman Kodak* sketched by the late A. Landucci *Kodak-Pathé* in a characteristic stance.

Asymmetry of an Integrating Sphere

O. H. Olson and D. A. Pontarelli

Integrating spheres are used extensively in reflectometers; therefore, it is important for the operator to be familiar with features that may lead to erroneous results during routine operation. This paper discusses an asymmetry present in the integrating sphere of the General Electric recording spectrophotometer, an excellent instrument widely used in reflectometry and color work.

Introduction

In one phase of an investigation of metal surfaces, a General Electric recording spectrophotometer was employed for measuring spectral reflectance. Variation of reflectance value with sample orientation was observed for polished silver, gold, copper, platinum, and stainless steel. The variation was most pronounced for satinlike finishes, whereas bright mirrorlike surfaces showed a negligible effect and an aluminized front surface mirror showed no effect. Our discussion will be confined to silver finishes designated as "satin" and "bright." The surfaces were prepared by buffing on a cloth wheel, which leaves fine rectilinear scratches on the surface. The pattern is detectable by visual examination and, under magnification, is seen to consist of small well-orientated grooves.

Reflectance curves for the silver surfaces are shown in Fig. 1. In each graph, the upper and lower curves show the extremes of reflectance observed for all orientations of the sample. Corresponding to the maximum and minimum values, the grain of the sample is oriented parallel and perpendicular, respectively, to the horizontal plane of the instrument. The intermediate curve is the reflectance when the grain of the sample is oriented 45° to the horizontal. Effects similar to these have been reported for textiles by Nutting,[1] who concluded that the average of the 2 readings represents the true reflectance value.

Polarizing Photometer

The components of the General Electric recording spectrophotometer optical system that influence reflectance values of metals are the flicker photometer and the integrating sphere. The photometer is shown diagrammatically in Fig. 2. The monochromatic radiation that is incident on the rotating plane polarizer of the flicker photometer is plane polarized in 2 mutually perpendicular planes. The rotating plane polarizer modulates each of the beams and continuously changes the angular orientation of the plane of polarization. One of the beams leaving the polarizer is imaged on the test sample and the other, on the reflectance standard. As a consequence of this arrangement, the radiation that is incident on the sample is plane polarized with the intensity maximum 90° out of phase with the intensity maximum of the radiation incident on the standard. Therefore, the plane of polarization and the intensity of the radiation incident on the standard and the sample are continuously changing with time, and this causes a particular plane of polarization to be associated with a maximum intensity, which in turn results in preferential illumination of the sample.

The polarization condition of the sample illumination is significant in explaining the reflectance values measured on grained surfaces, which in a highly polished state exhibit reflectance curves dependent upon the angle of incidence and state of polarization of the incident radiation. As is well known, the reflectance curves for the 2 polarized components are different at almost all angles of incidence. This effect is useful in explaining the dependence of the General Electric recording spectrophotometer reflectance value of a grained polished metal upon the angular orientation of the sample in the reflectance port.

The grain may be considered as steep-sided grooves which may be positioned parallel or perpendicular to the plane of polarization of incident radiation. With the grooves orientated perpendicular to the plane of polarization, the plane of incidence of the groove sides is parallel to the plane of polarization, so that the parallel reflectance component is more prominent and leads to a

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Received 25 July 1962.

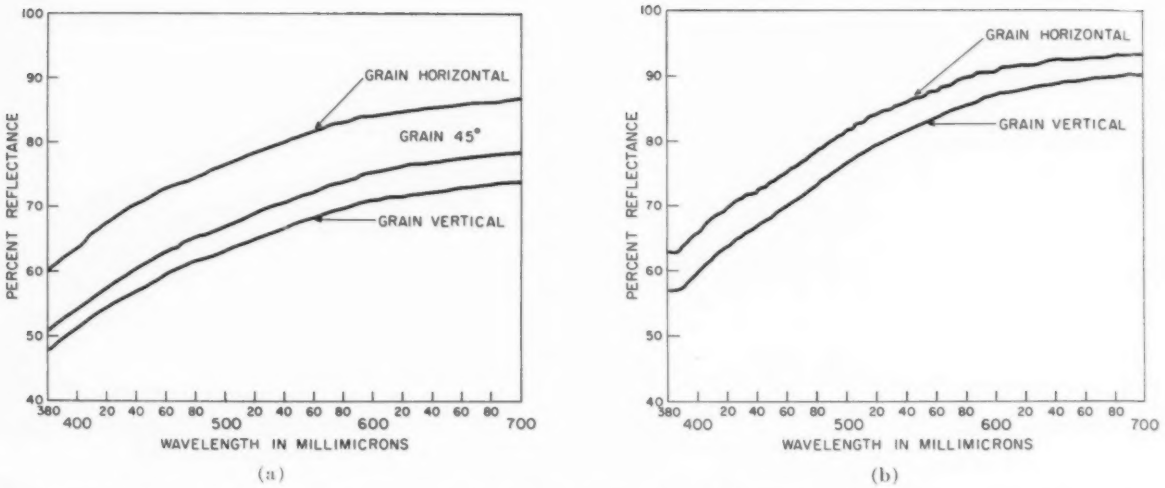

Fig. 1. (a) Reflectance of satin-finish silver, without retardation plate; (b) Reflectance of bright-finish silver, without retardation plate.

low value of reflectance. Conversely, when the grooves are orientated parallel to the plane of polarization, the perpendicular component is more prominent, and one measures a high reflectance value. This reasoning has been applied to the extremes of the reflectance, but is equally valid for the intermediate values.

These polarization effects may be eliminated by irradiating the sample with circularly polarized radiation. This is accomplished by insertion of a thick quarter-wave (retardation) plate behind the rotating polarizer and rotating it with the polarizer. The phasing of the instrument is not disturbed by this attachment, which is supplied by the General Electric Company.

Asymmetry of the Integrating Sphere

Figure 3 shows the reflectance curves obtained for the satin finish when a retardation plate was employed and the orientations of the sample were identical to those used to obtain Fig. 1. If polarization were the only cause of the reflectance discrepancy shown in Fig. 1, then the retardation plate would eliminate it, and the curves of Fig. 3 would coincide. Similar curves for the lightly scratched bright silver surface do coincide. The above experimental data suggest some asymmetry in the integrating sphere, which is sensitive to changes in the light reflected from the sample brought about by the

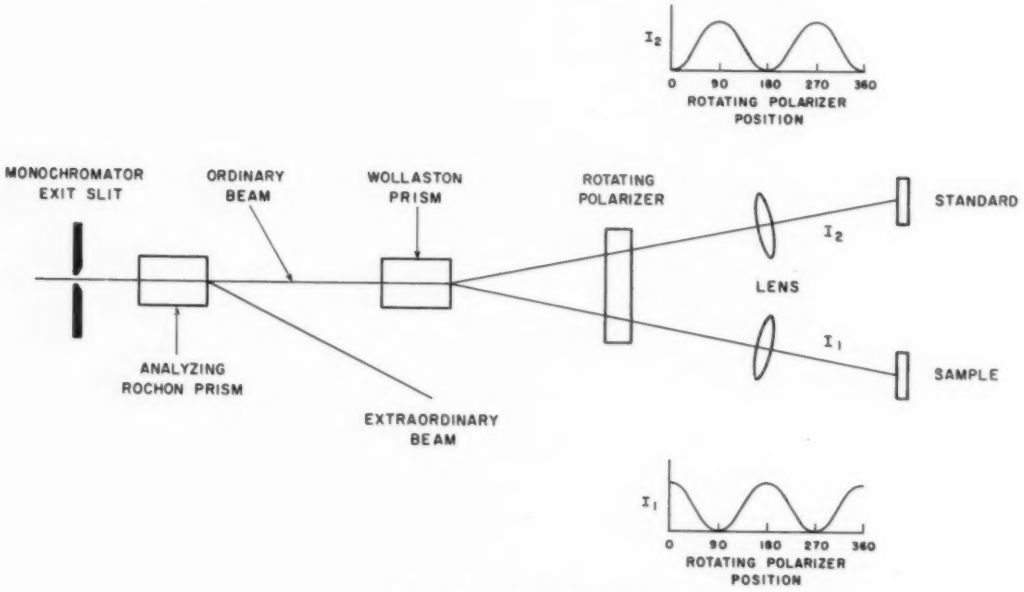

Fig. 2. Polarizing photometer.

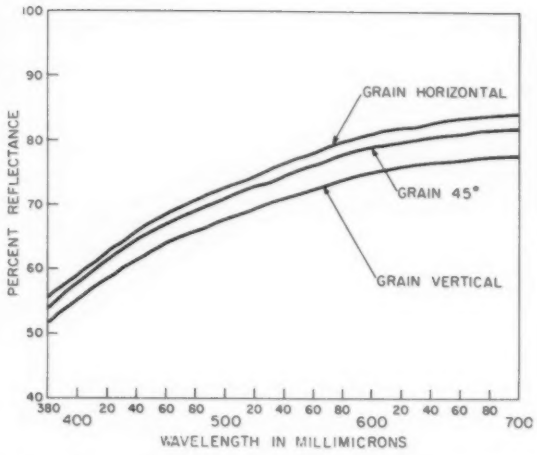

Fig. 3. Reflectance of satin-finish silver, with retardation plate.

physical structure of the grooves. The angular divergence of reflected radiation in planes parallel and perpendicular to the grooves was investigated by means of a goniophotometer. Goniophotometric curves for normal incidence are presented in Fig. 4. For the satin finish there is a large beam divergence in the plane perpendicular to the grain and a smaller divergence in the plane parallel to the grain, whereas for the bright finish the divergence is small and the same for both orientations. This result supports the data obtained with the retardation plate and strongly suggests the presence of some asymmetry in the integrating sphere.

Top and side views of the integrating sphere are shown in Fig. 5. Radiation reflected by the sample (and standard) is integrated by multiple reflections from the sphere walls. A photocell mounted below the sphere views the upper portion of the sphere wall through a light pipe, which extends for about two-thirds of the sphere diameter. The highest reading with circularly polarized light (retardation plate incorporated) occurs when the grain orientation is horizontal, as discussed above. In this orientation the maximum divergence of the reflected radiation occurs in the vertical plane, so that the area of the sphere viewed by the detector receives a disproportionately large sampling of the reflected flux. When the grain pattern is vertical the minimum divergence of the reflected radiation occurs in the vertical plane, so that the area viewed by the detector receives a disproportionately small sampling.

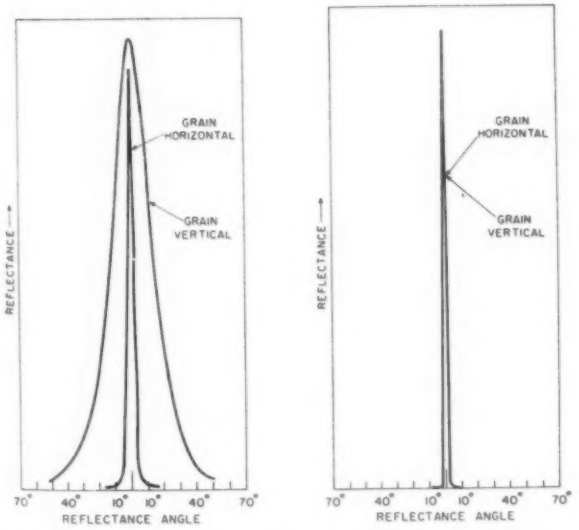

Fig. 4. Left—Goniophotometric curves of satin-finish silver; right—Goniophotometric curves of bright-finish silver.

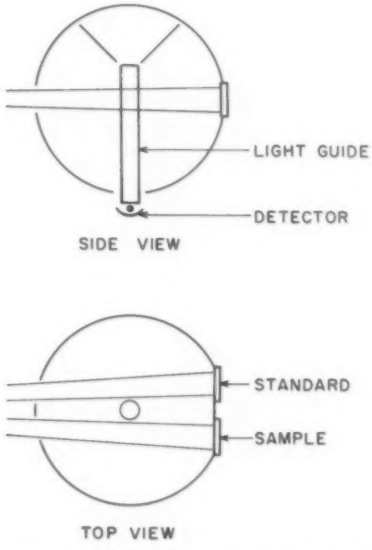

Fig. 5. Geometry of General Electric recording spectrophotometer sphere.

Conclusion

This paper has attempted to demonstrate that the integrating sphere of a General Electric recording spectrophotometer has an inherent asymmetry which becomes manifest when reflectance samples have pronounced directional surface patterns. In these instances, the use of a retardation plate fails to eliminate the discrepancy in reflectance readings brought about by reorientation of the sample in its own plane. It points up the need for caution when dealing with samples that possess a surface structure.

It should be pointed out that the General Electric instrument is not unique in this respect. Practically all integrating spheres are possessed of some asymmetry that should be investigated to discover how readings are affected by its presence.

Reference

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THE METRIC SYSTEM

See From the Editor page 616

OUR NEW AGE
by Athelstan Spilhaus
AT FIRST, MAN USED HIMSELF AS A MEASURE — UNITS WERE ...
HAND
SPAN
FOOT
INCH
YARD
SO LATER, ALL WERE COMPARED TO THE —
"INTERNATIONAL STANDARD METER"
—BUT PEOPLE COME IN DIFFERENT SIZES...
—AND TWO YEARS AGO THIS WAS DEFINED AS 1,650,763.73 WAVE LENGTHS OF ORANGE LIGHT FROM KRYPTON 86
TM & © All rights reserved The Hall Syndicate, Inc.
BUT, EVEN KNOWING WHAT THE OLD UNITS MEASURE, THEY STILL CAUSE COSTLY CONFUSION!
1.05671 liquid quarts or .908102 dry quarts = 1 liter.
1 gram = 15.432356 grains or .03215074 ounce
.4535924277 kilogram = 1 pound avoirdupois = 256 drams = 7,000 grains
LENGTH
VOLUME
LITER
METER
WEIGHT
KILOGRAM
ONE LITER FILLED WITH WATER
THE METRIC SYSTEM OF UNITS, WHICH GOES IN 10's AND RELATES LENGTH, VOLUME AND WEIGHT SIMPLY, IS USED BY SCIENTISTS EVERYWHERE AND BY EVERYBODY IN 100 COUNTRIES — BUT NOT BRITAIN AND THE UNITED STATES!
IT WAS STARTED IN THE FRENCH REVOLUTION AND ADOPTED BY RUSSIA AFTER THE 1917 REVOLUTION — WILL IT TAKE A NEW PEACEFUL AMERICAN REVOLUTION TO GET US IN STEP?
FRANCETTE

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Jet-Controlled Arc: I, Excitation of Second Spectra

Kenneth H. Thygesen and Frank L. Moore, Jr.

A new spectroscopic light source, which is essentially an enclosed dc arc with annular jets of gas sweeping past each electrode, is described. The composition and pressure of the carrier gas of this source can be chosen so that the character of the spectra obtained range from similarity to open-arc spectra to Schuler-lamp spectra. The effects of source conditions on the excitation of Cu I and Cu II spectra are discussed. Spectrograms are included which illustrate the usefulness of a stigmatic image in differentiating between atomic and ionic spectral lines.

An investigation of the effects of gaseous atmospheres on the excitation of spectra in a jet-controlled arc has led to the development of a new spectroscopic light source. The source is an enclosed dc arc in which an annular jet of gas surrounds each electrode. This source is simple to operate and has been used to excite second spectra of cathode samples.

The jet is a device which directs an annular flow of gas around the electrode of an arc. This flow of gas serves to reduce flaring, cool the electrode, and stabilize the arc column.[1] It also performs a cleansing action by rapidly carrying away from the arc particles that have been eroded from the electrodes and gases that have evolved from the electrodes.

Preliminary work using carbon-dioxide gas and anode excitation of powdered samples showed that air could not be excluded completely from the arc by use of either single or opposed jets alone. (CN-band emission was used as the criterion for the presence of air.) In order to insure knowledge of gas composition in the arc, the system of opposed jets was enclosed in a gas-tight chamber. The use of a sealed chamber also allows maintenance of gas pressure at any desired value. Two variations of chamber design have been used—one in which the electrodes may be continuously fed into the arc and one in which the electrodes are fixed. When a gas not containing oxygen is used, there is no appreciable anode erosion or slow-cathode erosion. This allows fixed electrodes and a completely sealed chamber. A spark must then be used to initiate the arc.

The authors are with Clarkson College of Technology, Potsdam, New York.

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Portions of this paper are taken from a master's thesis submitted by K. H. Thygesen to Clarkson College of Technology.

Apparatus

Figure 1 illustrates the construction of the fixed-electrode-source chamber and the detail of the lower-end-plate jet assembly. The lower-end plate, chamber cylinder, and jets are made from aluminum and brass, and the top-end plate and clamping studs are insulators. Rubber O-rings provide sealing. The chamber cylinder has side tubes for a manometer connection, a quartz window, and a viewing window.

The gas enters the system through the gas-inlet chamber, passes through the electrode guide and jet nozzle into the chamber, and leaves the chamber through the exhausts in the lower-end plate. When gas pressures below atmospheric pressure are to be used, two vacuum pumps are connected through stopcocks to the chamber exhausts. The chamber pressure and the gas-flow rate are controlled by adjusting the supply pressure, a stopcock between the supply and the chamber, and the stopcocks between the chamber and the vacuum pumps. This system is capable of maintaining a sufficient flow rate at pressures down to 15 cm Hg.

For normal operation of the source, the lower (sample) electrode is set to protrude about 2 mm above the jet nozzle, and the upper electrode is set to give an arc gap of about 3 mm. With the arc running, the gas-flow rate is adjusted until the arc assumes a cylindrical shape between the electrodes. If the velocity of gas flow past the electrodes is too low, the arc tends to wander and flare. An excessively high gas velocity also causes instability. It may be noted that with two jets in operation not only is there more efficient electrode cooling than with one but also the arc appears to be more stable.

All spectrograms were taken with a quartz Littrow spectrograph. A quartz condensing lens was also used,

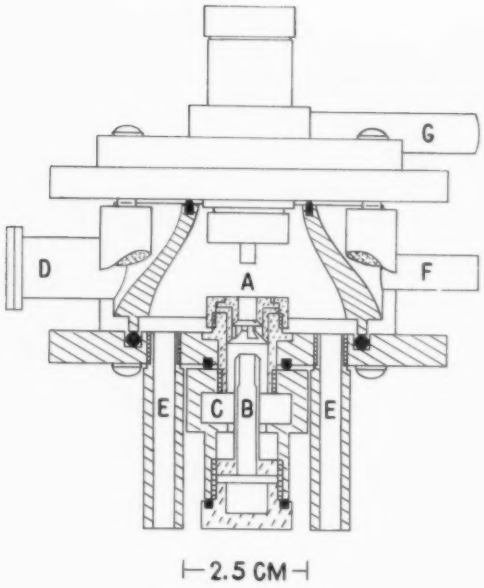

Fig. 1. Scale diagram of source chamber with detail of lower-end plate and jet assembly. A—jet nozzle and electrode guide, B—electrode holder, C—gas-inlet chamber, D—light exit, E—chamber exhausts, F—manometer connection, G—gas inlet.

to form an image of the arc at the slit of the spectrograph. The procedure images the arc at the plate position; but because of dispersion in the condensing lens, the image is stigmatic only over a limited wavelength range corresponding to a particular position of the condensing lens.

Anode Excitation

In order to determine the characteristics of this source, it was decided to photograph the spectrum of copper under various source conditions. Copper was chosen because the spectra of copper are well known,[2,3] and there is no problem in obtaining reasonably pure copper.

Spectrograms were taken of the arc between a solid copper anode and a carbon cathode in atmospheres of carbon dioxide, argon, and argon-oxygen mixtures. In each case, the gas was allowed to exhaust into the air so that the pressure of the gas in the chamber was approximately atmospheric. It was found that the excitation of copper in carbon dioxide is essentially the same as in air. The Cu I spectrum was strongly excited, and there was little excitation of Cu II. When the arc was run in argon at a current of 5 A, only spectral lines of argon were detected; however, when the current was raised to 10 A, the resonance lines of Cu I as well as the argon lines were detected. A mixture of oxygen with argon caused the excitation of most argon lines to be quenched and the Cu I spectrum to be excited strongly.

These observations made with the sample in the arc

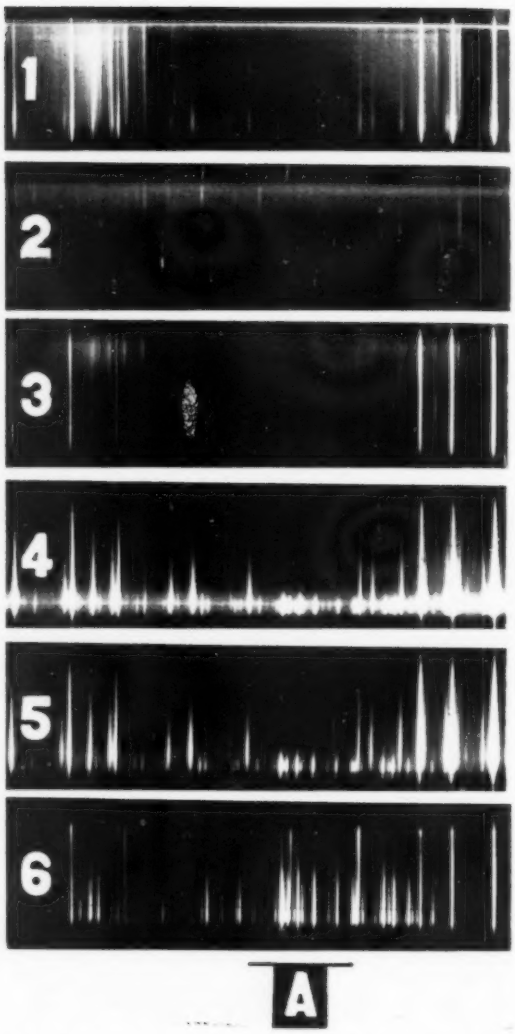

Fig. 2. Spectra of copper samples in the wavelength range 4590–5170 Å. These spectrograms were obtained with the enclosed arc source, with the sample electrode at the bottom, and:

No.	Gas	Pressure (atm)	Current (A)	Exposure time (sec)	Sample
1	CO_2	1	10	2	Anode
2	Ar	1	4	8	Anode
3	CO_2	1	9	2	Cathode
4	Ar	1	4	8	Cathode
5	Ar	1/2	4	10	Cathode
6	He	1/2	3.5	15	Cathode

The wavelength range indicated by A is the range 4865–5015 Å. All lines appearing above A are Cu II lines. The strong lines in Nos. 1 and 3 are Cu I.

anode indicate a limit in the excitation energy that can be given to a sample atom when a gas containing oxygen is used. That is, with carbon dioxide or an argon-oxygen mixture as the arc atmosphere, the high-excitation-energy Cu II lines are not detected.

These observations also indicate that under certain conditions atoms of the anode material do not enter the arc in detectable quantities. The arc in argon at a current of 5 A or less radiated Ar I and most of the strong Ar II spectral lines but no copper spectral lines (see Fig. 2, No. 2). When the current was raised to 10 A, the temperature at the anode apparently became so high that a detectable amount of copper could leave the anode surface.

Cathode Excitation

An attempt was made to operate the arc in helium and argon, using a solid copper cathode and a carbon anode, but the cathode spot would migrate to the jet nozzle rather than stay on the copper electrode. In order to hold the cathode spot on the electrode, it was found sufficient to use as the cathode a drilled carbon rod with copper placed in the sample cup. The sample was made flush with the top of the sample cup. The most suitable currents for operating the arc in helium or argon are in the range from 2 to 5 A.

A series of spectrograms was taken of the arc in carbon dioxide, an argon-oxygen mixture, argon, and helium at atmospheric pressure. The sample electrode was the arc cathode. These spectrograms showed that with either carbon dioxide or the argon-oxygen mixture, few Cu II spectral lines were excited. However, with argon or helium, many Cu II lines were detected.

Additional spectrograms were taken of the arc in argon and helium at pressures of one-half and one-third atmosphere. Analysis of all spectrograms taken with argon or helium showed that for any particular pressure more Cu II lines were detected with helium than with argon. It was also found that for each gas, more Cu II lines were detected when the gas pressure was reduced. A general enhancement of Cu II line intensity relative to Cu I line intensity occurs both as the gas pressure is reduced and on going from argon to helium. Spectral lines originating at the highest known levels of Cu II have been detected.

As previously mentioned, all spectrograms were taken with the arc imaged on the slit, and the image at the plate was reasonably stigmatic in the wavelength range 4500–5200 Å (see Fig. 2). This stigmatic image shows the spectral distribution of light originating along the arc column. It is interesting that the Cu II lines, in general, appear as wedged lines extending from the cathode and, in many cases, are not detectable near the anode. Also, some Cu I lines exhibit the opposite character, especially in helium at one-third atmosphere. For any of the spectrograms taken with cathode excitation in which Cu II lines were detected, it is in the region of the arc near the cathode that the greatest enhancement of Cu II and suppression of Cu I occurs.

A spectrogram was also taken with vanadium as the cathode sample, and it gave results similar to those obtained with copper. The vanadium arc was run in helium at one-half atmosphere. The VI lines were suppressed while VII spectrum was enhanced. The enhancement of VII resulted in the detection of about as many new VII lines as were previously identified in the 2500–3000 Å region.[4]

Conclusion

A source has been developed that can be altered rapidly to yield excitation similar to that of either the open dc arc or the Schuler lamp. The source has the advantages associated with the flow of gas past the electrodes, and it is easy to control the pressure of the conducting gas. One distinct advantage of this source over the Schuler lamp is that the arc can be imaged on the spectrographic plate to aid in differentiating atomic and ionic spectral lines. The lines of higher-excitation energy which originate near the cathode appear as wedged lines extending from the cathode. In this investigation, the Cu II lines appeared wedged from the cathode, and some Cu I lines appeared wedged in the other direction, although most Cu I lines appeared as full lines.

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4. W. Wojcik, Master's Thesis (Clarkson College of Technology, 1962).

Masers will be featured in the August issue

Some of the papers to appear in subsequent issues

Overhauser and Jeffries-Abragam Effect in a Four-Level System—*Narchal and Barker*

Spurious Harmonic Generation in Optical Heterodyning—*Cummins, Knable, and Yeh*

Interferometric Measurement of Vibration Amplitudes—*Bowie*

Infrared Transmission through Fogged Salt Windows—*Morrow and Turk*

A Simple Grating Calibrator for the Visible and Vacuum Ultraviolet—*Hammer, Arakawa, and Birkhoff*

Photorefractometer II. Measurement of N and K—*Kapany and Pontarelli*

Lighting Parameters and Generalized Characteristics of Xenon Lamps—*Marshak*

The Use of Polarized Infrared Radiation in Magneto-optical Studies of Semiconductors—*Palik*

An 8–14 μ IR Astronomical Photometer—*Westphal and Murray*

An Optical Null Double-Beam Double-Pass IR Spectrophotometer—*Minami*

A Photomultiplier Circuit for Precision Spectrophotometry—*Budde*

Large-Scale Photoelectric Planimeter for Leaves—*Carman*

A New Method for High-Speed Motion Picture Photography of Transparent Drops—*Pfeiffer*

Photometric Accuracy of Infrared Spectrophotometers—*Stewart*

Infrared Dispersion of Some Oxide Glasses—*Malitson et al.*

Study of the Fabrication of Aspherical Surfaces—*Sakurai and Shishido*

Transmission of Isotropic Radiation Across An Interface Between Two Dielectrics—*Stern*

Isosceles Total Internal Reflectors as Optical Elements—*Rothstein*

Test of Theoretical Absorption Band Model Approximations—*Burch and Williams*

Brighter Spectrographic Images by the Use of Anamorphic Optics—*Eisner*

Optics in Norway—*Hisdal and Omholt*

Use of an Analog Computer in Side-on Arc Spectroscopy—*Shumaker and Yokley*

The Evaporation Rate of Filament Material from Alternating Current Heated Filaments—*Wilson*

A New Condenser for a Sun-Powered Continuous Laser—*Keck, Redmann, White, and DeKinder*

Performance of a cw Neodymium Laser—*Keck et al.*

Attenuation by Ozone and the Earth's Albedo in the Middle Ultraviolet—*Green*

Tilted-Plate Interferometry with Large Plate Separations—*Moos et al.*

Double Monochromator Systems—*Christensen and Potter*

Experiments with the Optical Excitation of Mercury Vapor for the Production of Isolated Fluorescence—*Zito and Schraeder*

Application of the Senarmont Polariscope to Analysis of Optical Light—*Hellerstein*

Hole Burning Model of Oscillation of Ruby Laser—*DeMaria and Gagosz*

Electro-Optic Light Modulation with Cubic Crystals—*Buhrer, Bloom, and Baird*

Observations of Near Infrared Radiation from the Solar Atmosphere—*Taylor and MacQueen*

Irradiance on a Flat Object Underwater—*Tyler and Shaules*

Kirchhoff Diffraction Pattern Calculations—*Moore*

Interference Rings in Ruby Maser Beams—*Stoicheff and Szabo*

Electronic Flash Illumination of a Large Wilson Cloud Chamber—*Edgerton*

Interference Filter Spectrometer for Low Intensity Extended Sources—*Carter, MacRae, Nelson, Birkhoff, and Arakawa*

A Universal Spectrophotometer—*Kaye*

The Atomic Spectra of the Rare Earths: Their Presence in the Sun—*Moore*

The Observation of Extraphotographic Infrared Atomic Emission Spectra—*Humphreys and Paul*

The Review of Reviews of Atomic Spectroscopy—*Meggers*

Recent Work on the Second Spectra of Some Iron Group Elements—*Velasco, Iglesias, Gullon, and Diago*

An Image Inverter for Spectral Projector Comparator—*Hodge and Horey*

The Spectra of the Doubly and Triply Ionized Rare Earths—*Dieke and Crosswhite*

Spectroscopic Line Profile Studies of Long, Magnetically Confined, High-Current, Steady-State Vacuum Arcs—*McNally and Skidmore*

Infrared Transmission of the Atmosphere to Solar Radiation—*Gates and Harrop*

The Stressed-Plate Shutter: A New Moderate-Speed Electro-Optical Light Modulator—*Hauser, Smith, and Marlowe*

A Method for Measuring the Distortion of Photographic Objectives—*Zimmerman*

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Men and Milestones in Optics
II. Thomas Young

E. Scott Barr

People concerned chiefly with physical optics will probably agree with Henry Crew[1] that "the one outstanding optical discovery which the world owes to Thomas Young was that two rays of light incident upon a single point can be added together to produce darkness at that point." M. H. E. Tscherning (who translated and edited *Oeuvres Ophtalmologiques de Thomas Young*, 1894) called him "the founder of physiological optics" for his work in 1793 on the accommodation of the eye,[2] the first description and measurement of visual astigmatism,[3] his determination for the first time of the optical constants of the human eye,[3] and his hypothesis concerning the mechanism of color vision.[4] Lens designers have reason to admire him for his treatment of refraction.[5]

Let us consider briefly each of these major contributions.

As Crew points out, the originator of the wave theory is not known, although the claim of Robert Hooke (based on his *Micrographia*, 1665) is probably as valid as that of anyone else. While Hooke's comments were based almost entirely on speculation, Huygens' 1690 hypothesis had considerably more experimental data to explain, for in 1669 Bartholinus had discovered double refraction, in 1675 Römer had verified the finite speed of light, and Huygens himself had discovered polarization. With this information in mind, Huygens proposed his idea that light consisted of pulses (presumably longitudinal) and devised his method of constructing wave fronts to explain the propagation of light. In 1704 Newton's *Opticks* appeared and we learn from it that, although he did in a way accept the general idea of periodicity, the "absence" of diffraction effects convinced him that a corpuscular theory was more probably correct. With the tremendous prestige of Newton behind it, this theory persisted almost unchallenged (except by Euler) through the eighteenth century.

Presumably as a consequence of his interest in music, Young turned his attention to sound and when he was twenty-seven published his first major (44-page) paper, "Outlines of experiments and enquiries respecting sound and light,"[6] in which he advanced his principle of superposition, pointed out analogies between sound and light, and supported Huygens' theory. Then, on 12 November 1801, Young gave his second Bakerian Lecture before the Royal Society in London on "The Theory of Light and Colour."[4] Using water waves as an analogy, Young said, "I maintain that similar effects take place whenever two portions of light are thus mixed; and this I call the general law of the interference of light." Newton's own measurements of the rings formed by contact between a convex lens and a flat surface were used by Young to obtain quite accurate values for wavelengths of light. In this connection Young refers to Hooke's work and says that in it was "a passage which might have led me earlier to a similar conclusion." His next paper, "An account of some cases of the production of colour, not hitherto described,"[7] provided the explanation for the dark center of the ring system, and told how sassafras oil between a crown lens and a flint plate gave the predicted bright center.

Finally, in the Bakerian Lecture, "Experiments and calculations relative to Physical Optics,"[8] which he gave on 24 November 1803, Young was able to proffer more than mere speculations, for he had devised an experimental proof of the correctness of his theory. He reflected a small beam of sunlight into a dark room and placed in this beam a strip about 0.85 mm wide, cut from a card. Fringe measurements gave wavelengths which correlated with Newton ring values, thus providing quantitative evidence for the correctness of his interference theory and validating the wave theory of light. His more familiar double-slit experiment is described in Lecture 39 in his famous *Lectures on Natural Philosophy*.[9] Extracts from these original descriptions are to be found in Magie and in Shamos.[10]

It would be natural to assume that the cogency of Young's reasoning and the convincing nature of his experimental verifications would have brought him wide and immediate acclaim, but this did not happen,

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Fig. 1. Thomas Young, from the painting by Sir Thomas Lawrence. This reproduction is from the engraving prepared by Henry Adlard, which serves as the frontispiece of *Six Lectures on Light* (delivered in America in 1872–3), by John Tyndall, 3rd ed. (D. Appleton and Company, New York, 1898).

largely due to the malice of one man. Back in 1798 Young had casually made disparaging comments on a mathematical paper by Henry Brougham (1778–1868, later Lord Chancellor), and he thereupon became Young's bitter and unforgiving enemy. Young's papers were attacked anonymously by Brougham in the *Edinburgh Review* in terms both abusive and sarcastic. Concerning the 1800 Bakerian Lecture he wrote, "As this paper contains nothing which deserves the name either of experiment or of discovery, and as it is, in fact, destitute of every species of merit . . . ." Young's 1802 paper was given similar treatment as "paltry and unsubstantial," and the Royal Society was urged by Brougham not to lower its standards by admission of Young's papers! The 1803 Bakerian Lecture brought the most invective of all: "We now dismiss, for the present, the feeble lucubrations of this author, in which we have searched without success for some traces of learning, acuteness, and ingenuity, that might compensate his evident deficiency in the powers of solid thinking, calm and patient investigation . . . ."

Despite Young's rather clumsy efforts to defend himself in his "Reply to the animadversions of the Edinburgh reviewer on some papers published in the Philosophical Transactions,"[11] which had almost no circulation at all (only one copy is said to have been sold), the scientific world did not adopt the wave theory. As a matter of fact, Young's reputation suffered considerably, and he had difficulty in finding a publisher for his *Lectures*. As a result of this episode, Young resolved to refrain in the future from any work in the sciences other than medicine. Although he was unable to keep this resolution, from then on he did usually write anonymously for the sake of his medical reputation among his patients.

During the ten years intervening between the publication of his *Lectures* and the appearance of Fresnel's papers, almost no one supported Young's theory. His friend Wollaston was dubious about it, William Herschel did not accept it, and Biot, Laplace, and Poisson actively opposed it. To make matters worse, the discovery by Malus in 1809 that light could be polarized by reflection even shook Young's own confidence. Having approached light through the study of sound, he still thought in terms of a longitudinal wave, as indicated in an article which he prepared in 1817 for the *Encyclopædia Britannica:* Arago and Fresnel also approached interference in terms of longitudinal waves.

Fresnel presented his first paper on interference before the Paris Academy of Sciences in October 1815 and it was published the following year. Not until November of that year did Fresnel learn of Young's work (through Arago). In May 1816 both Arago and Fresnel communicated with Young, and these three great minds were then jointly turned to the problem. Fresnel's brilliant memoir on diffraction in 1818 perfected the treatment of interference and won the warm praise of

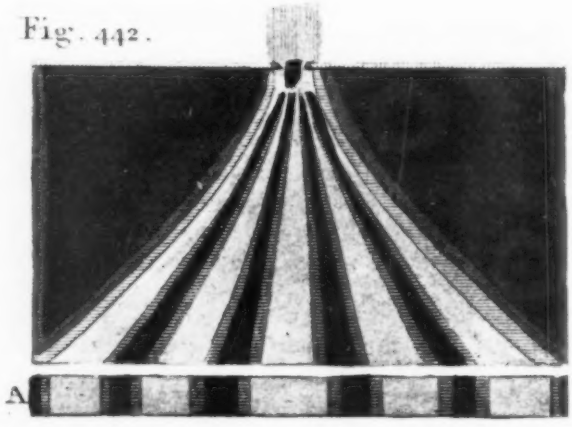


Fig. 2. The interference pattern observed by Young. From ref. 9, 1807 edition, Vol. I, Plate XXX, Fig. 442. (The original drawing is colored, green and black.)

Young (who, by the way, had considered that the diffraction pattern of a single slit was due to interference of light reflected from the two slit edges). With Arago's blessing, Fresnel continued his work on polarized light from 1816 to 1821. (A quarrel over Fresnel's work, by the way, ended the friendship between Arago and Biot.)

Fresnel claimed to have mentioned the possibility of transverse waves in a conversation with Ampère in 1816, and Young touched on the same possibility both in letters to Arago 1817–1818 and in one of his *Encyclopædia Britannica* articles. Even after Arago and Fresnel had carried out their experiments which showed that interference between beams of light polarized at right angles to each other was impossible, Arago—as he later admitted—lacked the courage to identify himself publicly with the idea of a transverse light wave. Young himself commented that the idea "is attended by one circumstance which is perfectly *appalling* in its consequences . . . only solids have a lateral resistance . . . so it might be inferred that the luminiferous ether, pervading all space, and penetrating almost all substances, is not only highly elastic, but absolutely solid!!!" Fresnel, however, went ahead and announced his belief that light waves were exclusively transverse in his 1824 memoir.

Although the wave theory was now fully developed, it was accepted reluctantly by many: John Herschel wrote in 1827 that Young's theory is "one which, if not founded in Nature, is certainly one of the happiest fictions that the genius of man ever invented to grasp together natural phenomena . . . it is, in fact . . . a succession of felicities, insomuch that we may be almost induced to say, if it be not true, it deserves to be so." As to the roles of Young and Fresnel, he expressed the opinion that "to separate them and assign to each his share would be as impracticable as invidious, so intimately are they blended together throughout every part of this system—early, acute and pregnant suggestion characterising the one; and maturity of thought, fullness of systematic development and decisive experimental illustration, equally distinguishing the other."[12]

In his 1801 Bakerian Lecture Young also presented his concept of the mechanism of color vision, and proposed red, yellow, and blue as the three "principal" colors. Apparently as a result of learning from Wollaston that red light mixed with green light gave a yellow sensation, Young changed to red, green, and violet in 1802.[13] Concerning Young's theory Clark Maxwell much later wrote, "It seems almost a truism to say that colour is a sensation; and yet Young, by honestly recognizing this elementary truth, established the first consistent theory of colour. Thomas Young was the first who, starting from the well-known fact that there are three primary colours, sought for the explanation of this fact, not in the nature of light, but in the constitution of man." Helmholtz rediscovered Young's work and amplified it into the Young-Helmholtz theory. In speaking of this early work of Young, he says, "The theory of colours, with all these marvellous and complicated relations, was a riddle which Goethe in vain attempted to solve; nor were we physicists and physiologists more successful. I include myself among the number; for I long toiled at the task, without getting any nearer my object, until I at last discovered that a wonderfully simple solution had been discovered at the beginning of this century, and had been in print ever since for any to read who chose. This solution was found and published by the same Thomas Young who first showed the right method of arriving at the interpretations of Egyptian hieroglyphics. He was one of the most acute men who ever lived, but had the misfortune to be too far in advance of his contemporaries."

Young's first Bakerian Lecture, on "The Mechanism of the Eye,"[3] was read before the Royal Society on 27 November 1800. With respect to it Sir John Parsons wrote, "I agree myself with Tscherning that Young's greatest and most original contributions to science are contained in his paper on the mechanism of the eye."[14] As mentioned above, Young had reported in 1793 on his earlier work on this problem—and as a result had been elected a Fellow of the Royal Society on 19 June 1794, at the age of twenty-one. In this paper are described the measurements Young made on his own eyes, using a modified compass put in contact with the sclerotic of his eye. He found his corneal radius to be 7.87 mm and computed his eyeball to be 23 mm long. By use of his version of the optometer (in connection with which he took the normal near point to be 20 cm) he found that his eyes were astigmatic, thus reporting the first observation of this eye defect. He also found that correction could be obtained by placing a lens obliquely in his line of sight. (George Airy showed in 1825 that a cylindrical lens could be used for this purpose.)

Another phase of Young's work in optics is described by Smith,[5] who wrote "The real testimony to the importance of Young's work in the field of geometrical optics is the fact that his equations are still used by optical designers one hundred and fifty years after he obtained them." Mention should also be made here of the instrument which he devised some time before 1810 and named the "eriometer," for the measurement of the sizes of minute particles and small fibers. His studies on atmospheric optical phenomena between 1803 and 1825 should be noted also.

Young's contributions to other fields of physics can be mentioned here only briefly. His studies of elasticity are memorialized by "Young's modulus" (though his own description of this quantity has been called "a model of cumbersome obscurity"[15]), and were related

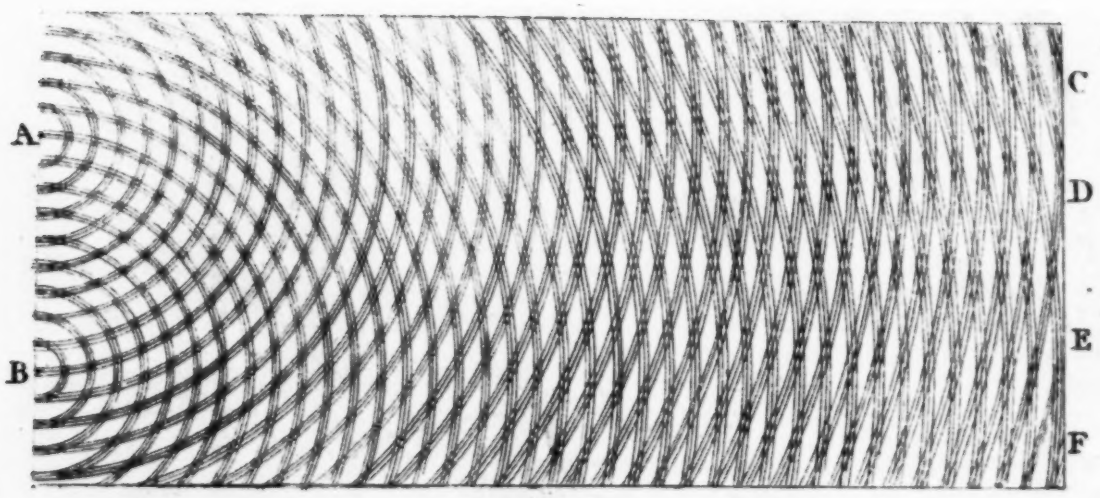


Fig. 3. Young's drawing to explain interference with two slits. From ref. 9, 1807 edition, Vol. I, Plate XX, Fig. 267.

to his investigations of the proper construction of arches and ships. He was involved with the standardization of lengths around 1818 and devoted much attention to measurements with the Kater pendulum, which led him into studies of fluid friction. These in turn led him to his investigation of the flow of blood in the body as a problem in hydraulics. As a by-product of his studies of cohesion and capillarity, he made the first estimate of the diameter of a molecule, but was off by a factor of one hundred. He introduced the use of the word "energy" in its modern technical sense.[18] Musical acoustics and the phenomenon of beats in sound (based on his principle of superposition) received some of his attention. He devised the ripple tank—Faraday later used one made by Young—and the kymograph. He took an interest in the problem of correcting the effects of a ship on its compass.

The most famous of Young's writings are the *Lectures on Natural Philosophy* mentioned above. The sixty lectures were prepared for presentation at the Royal Institution, 1801–1803. The first volume contains the lectures, with nearly six hundred diagrams and illustrations; the second volume includes reprints of several of his original papers and a classified list of about 20,000 references to pertinent literature. Taken together, these volumes provide an account of the subject which is not surpassed by any work in English before or since. Sir Joseph Larmor has praised them as "the greatest and most original of all lecture courses," and expressed the opinion relative to the bibliography that "no such authoritative catalogue, even of the select classical works of modern science of personal origin, is likely to appear again."[33] However, as mentioned above, Young had difficulty in getting them published and, since the publisher failed and was unable to pay Young the thousand pounds agreed upon, he had no return at all from them.

Despite their intrinsic merit, the lectures suffered from Young's inability to write in simple and understandable language, being—according to a contemporary—"worse calculated than any man I ever knew for the communication of knowledge."[20] He apparently realized this, for he wrote, "The most difficult thing for a teacher is, to recollect how much it cost himself to learn, and to accommodate his instruction to the apprehension of the uninformed."[19] This defect remained with him, for a report he later prepared for the Admiralty drew the comment, "Though science is much respected by their Lordships and your paper is much esteemed, it is too learned."[16]

The most important of his six other major works is probably his *Introduction to Medical Literature, including a System of Practical Nosology*, 1813. For each disease this work provided a list of pertinent references, assessed and summarized. The scope of his reading is indicated by the fact that entries in this list run into the thousands.

While Young's activities in the field of mathematics were relatively limited, he did become interested in computing some actuarial tables in 1816, and became a consultant for the Palladium Insurance Company in 1824 at a salary of 500 pounds (which he later requested be changed to 400 pounds, as the work did not involve as much time as he had anticipated).

Studies in the Latin and Greek classics brought Young renown in that field also. In connection with the samples of Greek letters which he prepared for John Hodgkins' *Calligraphia Graeca*, that author said of

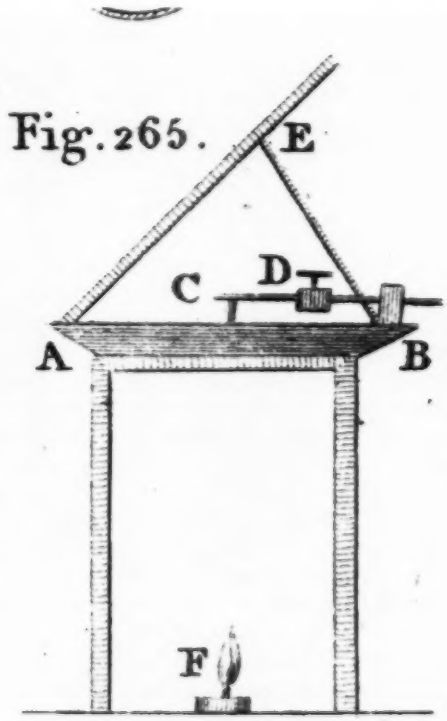
him, "he has achieved such skill in the Greek language as few others have done, and such elegance in forming Greek characters as scarcely any other man up till now."[34]

The challenge of the Rosetta Stone was taken up by Young in 1814 and, to quote from the tablet in his honor in Westminster Abbey, it was he who "first penetrated the obscurity which had veiled for ages the hieroglyphics of Egypt." He, of course, shares with Champollion the honor of deciphering the inscription. About 1827 he undertook the compilation of an Egyptian dictionary and worked on it as time permitted; this was his last work.

During his free time between 1817 and 1824 Young prepared a large number of articles for the *Encyclopædia Britannica* (begun in Scotland in 1771), but his agreement with the editor, Macvey Napier, in 1816 specified that they should be anonymous. However, he wrote Napier, "I could probably furnish you with some articles which you could scarcely obtain from other quarters; I should not refuse to do my best upon any subject in science."[21] He instrumented this amazing offer by suggesting as topics: Alphabet, Annuities, Attraction, Capillary Action, Cohesion, Colour, Dew, Egypt, Eye, Forms, Friction, Halo, Hieroglyphic, Hydraulics, Motion, Resistance, Ship, Sound, Strength, Tides, Waves, and anything medical! He actually provided forty-six biographies of scientists, which entailed much research on his part, and seventeen articles: his total contribution amounted to about 380 pages. Typical of the high quality of his articles is the one on Languages. This 33,000-word treatment gave an account of their origin and structure as well as their affinities. The existing languages were divided by him into five families: monosyllabic, Indo-European, Tartaric, African, and American. Citations were made of 23 authorities between 1555 and 1816.

It should be mentioned that many of the contributions by Young (about 75 journal articles, in addition to those in the *Encyclopædia*) were made more or less furtively for fear of criticism that he was neglecting his medical work. Similarly, some of his most important original work is presented in the *Lectures* with no indication of its originality.

Concerning Young's private life there are fortunately several reliable sources of information.[35] He was born in Milverton, near Taunton, on 16 June 1773, in the building which served as both residence and business place for Thomas Young, Senior, who was a banker and a cloth merchant. His mother was the niece of a prominent London physician, Richard Brocklesby. Both of his parents were Quakers, and Thomas, Junior, was the first of their ten children. During the greater part of his first seven years he lived with his maternal



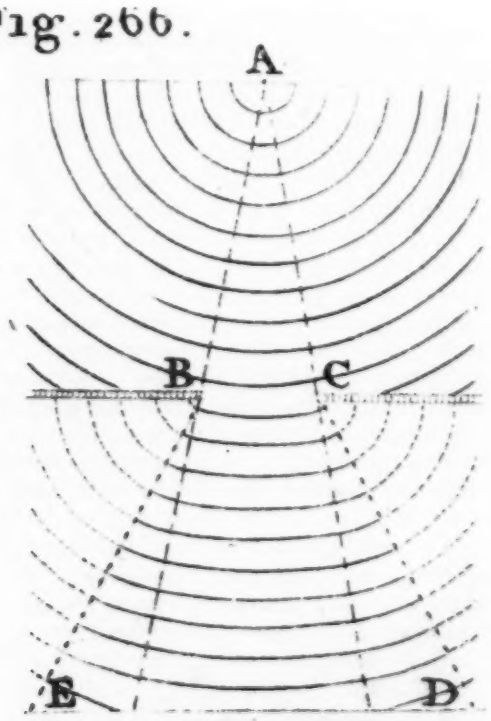


Fig. 4. Young's drawing of his ripple tank and a pattern obtainable with it. From ref. 9, 1807 edition, Vol. I, Plate XX, Figs. 265 and 266.

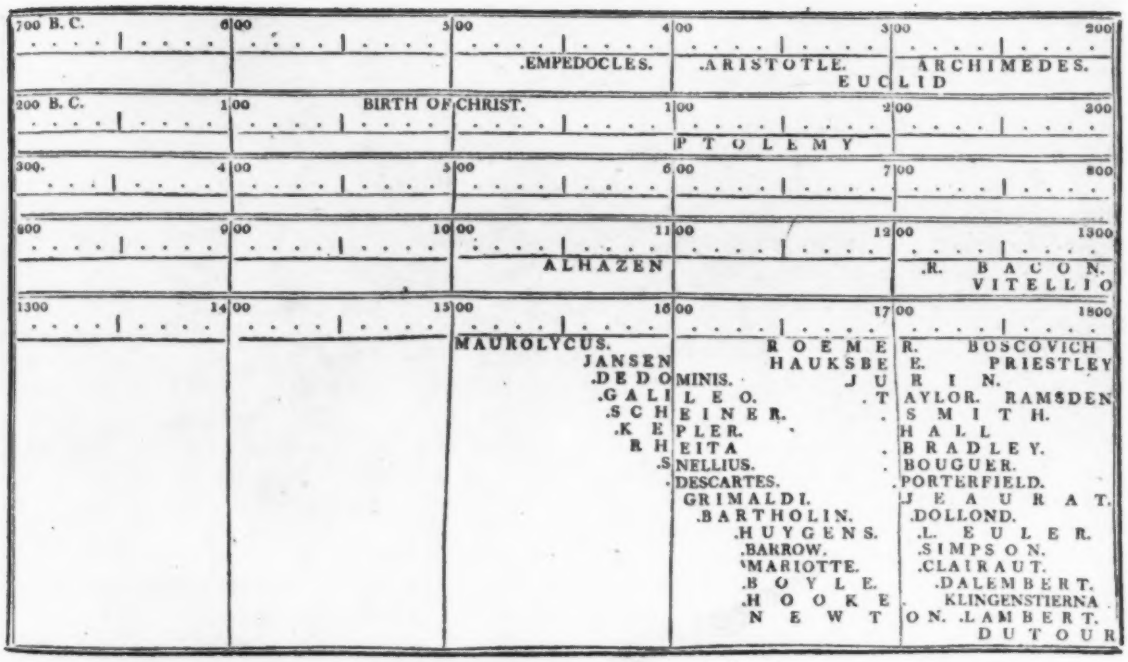


Fig. 5. Young's "chronology of optical authors," from ref. 9, 1807 edition, Vol. I, facing page 482.

grandfather, Robert Davis, who took a great interest in his education. His childhood is known through the autobiographical account written in Latin by him when fourteen, and the account is astonishing to say the least. By the time he was two he could read with considerable ease, and by the time he was four he had read the Bible through twice with the help of his grandfather and his aunt. Before he was five he had learned by heart Goldsmith's *Deserted Village*, and before he was six he had begun the study of Latin grammar and writing, in which he excelled. Except for two six-month periods at home, he spent the years between seven and thirteen at one or the other of two boarding schools, where instruction was chiefly in the classics. Informal study on his own gave him acq' aintanceship with some scientific books, a knowlege of Hebrew, French, and Italian, and several manual skills (such as lathe work, the making of telescopes, etc.).

At the age of fourteen he went to live with a friend of the family as a companion for Hudson Gurney, then twelve and a half, who became his lifelong friend: he remained there for five years. A tutor was provided by Hudson's father and a famous anecdote has it that when the tutor asked Young to demonstrate his penmanship by copying a sentence, he complied by writing it out in four or five different languages! (Arago[29] gives the number as nine: Peacock[28] puts it at fourteen!) In any case, at one time or another during his youth, Young learned Latin, Greek, Hebrew, French, Italian, Chaldee, Syriac, Samaritan, Arabic, Persian, Turkish, and Ethiopian! Despite the availability of the tutor, Young learned chiefly through independent study and had little confidence in any other method. He wrote one of his brothers, Robert, that, "it is in reality very little that a person who is seriously and industriously disposed to improve may not obtain from books with more advantage than from a living instructor . . . whoever would arrive at excellence must be self-taught."[30]

When nineteen, in 1792, he turned to the serious study of medicine, first in London and then in Edinburgh, where he studied under Black. While in Edinburgh, Young discarded some of the strict Quaker customs and attire and took up music, dancing, and theater attendance: he enjoyed the company of the ladies, but did not become serious with any of them. In 1795 he went to Göttingen for further study of medicine, but managed to work in some other things there as well. His daily schedule ran: 8—European history, 9—materia medica, 10—acute diseases, 11—(twice a week) private dancing lessions, 1—(twice a week) clavichord lessons and (twice a week) private drawing lessons, 2—Lichtenberg on physics, 3—horseback riding (four times a week), 4—diseases, 5—natural history, 6—(twice a week) dancing class and (twice a week) clavichord. He passed his medical examination there (without preparatory study!) in 1795. ("The examination lasted between four and five hours; the four examiners were seated round a table, well furnished with cakes, sweetmeats, and wine, which helped to pass the time agreeably . . . ."[22]) He completed his dissertation and de-

fended it in July 1796, then took a vacation trip with Thomas Wedgwood and John Leslie before returning to England in 1797.

Upon his return he found that new regulations prevented his practice of medicine and required further study there, at Cambridge (where he received the nickname, "Phenomenon" Young). That same year he became financially independent as a result of inheriting his uncle's fortune. He completed the necessary residence requirement in the spring of 1799 and launched his medical career. He was awarded his M.B. degree by Cambridge in 1803 and his M.D. in 1808, these dates being the earliest that he could submit his dissertations for them. In 1811 he was elected a staff member of St. George's Hospital, a position he retained for the rest of his life.

As a physician Young was largely unsuccessful. Although his medical care was generally adequate for his patients' needs, he was not popular. In spite of the fact that he was extremely competent, he lacked a manner which inspired confidence. As a result of his consistent truthfulness, his awareness of the uncertainty of diagnosis and of the possible later ill effects of an indicated treatment was communicated to his patients. He thus lacked the popularity of other physicians who prescribed "vigorous" measures with seeming assurance. Young was frustrated and hurt by his apparent failure in his chosen profession and his lack of popularity. His medical practice as a major activity extended only from about 1799 to about 1818.

Just after the turn of the century, before his medical practice was at all established, Young spent two years with the Royal Institution. Largely at the instigation of Count Rumford, the Royal Institution had been established in January 1800, with a Professor Garnett holding the Chair of Chemistry and Natural Philosophy. Upon his resignation in 1801, Humphry Davy took over the duties in chemistry and Young those in Natural Philosophy (as well as editorship of the *Journal*). There Young prepared his famous lectures, three each week for about twenty weeks at a time. Their scope, completeness, and originality make them an impressive intellectual achievement, but as given they were not successful, for the material was too compressed and predicated too much background of the listener. Young spoke with great precision and rapidity, using unfamiliar terms freely—and talking well over the heads of his audience! As might be expected, the situation proved to be an impossible one and Young resigned, with good feelings on both sides, in the middle of 1803.

In his later years Young served on a variety of governmental committees concerned with both basic and applied science. In 1818 he became Secretary of the Board of Longitude and Superintendent of the *Nautical Almanac*.

Tributes to the true genius of Young have been paid by many. Ames, of Johns Hopkins University, put it very simply: "Thomas Young was the last of the men who knew everything."[1] Davy wrote of him, "He was a most amiable and good tempered man . . . of universal erudition, and almost universal accomplishments. Had he limited himself to any one department of knowledge, he must have been the first in that department. But as a mathematician, a scholar, a hieroglyphist, he was eminent, and he knew so much it was difficult to say what he did not know."[31] As Tscherning pointed out, "For his own reputation it would certainly have been better if Young had completely developed but one of his ideas. But for the advancement of science it was better that he did as he did."[17] Young's insight, originality, and versatility made it possible for him to make discontinuous advances in many fields and in this way, by providing the foundations for the work of many others, he more than compensated for anything lost through the absence of exhaustive investigations.

The experimental confirmation of theoretical conclusions seemed to Young to be largely wasteful: he was never fond of repeating experiments, or much inclined to originate new ones. However necessary experimental work might be, he felt that after a fact was established, experimentation required a great sacrifice of time that might be better used. Relative to the wave theory, he asserted with satisfaction in his 1801 Bakerian lecture, "Nor is it absolutely necessary in this instance to produce a single new experiment; for of experiments there is already an ample store."[32] He said of himself that, "Acute suggestion was then, and indeed always, more in the line of my ambition than experimental illustration,"[23] and "For my part, it is my pride and pleasure, as far as I am able, to supersede the necessity of experiments, and more especially of expensive ones."[24] He carried his opinion of the secondary importance of experiment to the point of objecting to increasing a fund left by Wollaston to the Royal Society to help experimental investigations.

There remains only to add something about Young as a person, beyond what may have been inferred from the foregoing. His Quaker training as a youth gave him a passion for truth; he could not tolerate exaggeration or even high coloring in conversation or writing. His upbringing gave him self-reliance and independence to an unusual degree, and he had a compulsion to make good use of his time. Just before his death, although confined to his bed, he continued work on his Egyptian dictionary. He explained to a worried friend that it was a pleasure rather than a chore, and that if he should finish it, it would be a satisfaction, but that—as seemed more probable—if he should not, it would still give him the great satisfaction of *never having spent an idle day in his life!*

Despite these strict principles, Young thoroughly en-

Fig. 6. Thomas Young, drawn by T. Brigstocke, from a medallion by Sir Francis Chantrey (in Westminster Abbey), and engraved by J. J. Chant, from the frontispiece to Volume I of the *Miscellaneous Works*. (Chantrey found that he was unable to produce a satisfactory bust of Young and was forced to substitute the medallion.)

joyed the good things of life. He showed no signs of the peculiarities which sometimes accompany genius, though he always had great confidence in his own ability. He was convinced that any man can do what any other man had done. He was an expert horseman, and once entered a contest of skill with a celebrated rope dancer. He had a very thorough understanding of art and a profound knowledge of the theory of music. He sang well and could play almost all musical instruments, including the Scotch bagpipe. He was fond of dancing, was a good conversationalist, and frequented the best society of London. The portrait of him painted by Sir Thomas Lawrence (Fig. 1) shows his appearance at the age of forty-eight.

Possibly much credit for Young's stability is due to his wife, who came from a cultivated and aristocratic family. She was a woman of sound common sense and was devoted to her husband's interests. Their marriage in 1804, when he was thirty-one and she was nineteen, had no issue, but was a singularly happy one: she survived him by thirty years. Apparently he was very close to her family, for he was interred in her family vault in Farnborough in Kent. From this circumstance and the almost complete lack of references to other members of his family, it would appear that he to some extent drifted away from his own family.

Early in January 1829, Young's health began to fail. He suffered from attacks of asthma and general weakness, but lingered on until 10 May 1829, when he died in his home in London. A post-mortem examination revealed an ossification of the aorta extending to the heart. The symptoms were those of a completely worn-out man, and were such as are usually encountered much later in life. Apparently his relatively early death at the age of fifty-six was the penalty of his incessant labors. A memorial to him was placed in Westminster Abbey at Mrs. Young's wish, and bears a tribute to him by his lifelong friend Gurney which includes the words, "A man alike eminent in almost every department of human learning, patient of unintermitted labour, endowed with the faculty of intuitive perception. . . ."

Finally, three excerpts from letters by Young are most revealing:

> The longer a person has lived the less he gains by reading, and the more likely he is to forget what he has read and learnt of old; and the only remedy that I know of is to write upon every subject that he wishes to understand, even if he burns what he has written.[25]
>
> I like a deep and difficult investigation when I happen to have made it easy to myself, if not to all others; and there is a spirit of gambling in this, whether, as by the cast of a die, a calculation *à perte de vue* shall bring out a beautiful and perfect result, or shall be wholly thrown away. Scientific investigations are a sort of warfare, carried on in the closet or on the couch against all one's contemporaries and predecessors; I have often gained a signal victory when I have been half asleep, but more frequently found, on being thoroughly awake, that the enemy had still the advantage of me, when I thought I had him fast in a corner, and all this you see keeps me alive.[26]
>
> It is well for me that I have not to live over again: I doubt if I should have made so good a use of my time as mere accident has compelled me to do. Many things I could certainly mend, and spare myself both time and trouble; but, on the whole, if I had done very differently from what I have, I dare say I should have repented more than I now do of any thing; and this is a tolerable retrospect of forty years of one's life. I have learned more or less perfectly a tolerable variety of things in this world; but there are two things that I have never yet learned, and I suppose never shall — to get up and to go to bed. It is past twelve o'clock, but I must write for an hour longer.[27]

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35. See especially from the above 15, 20, 29, 30, and 31. Arago's memorial address is also available in the 1869 *Report of the Smithsonian Institution.* "Thomas Young, the man and physician," prepared in connection with the observation of the centennial of Young's death by the Optical Society of America [J. Opt. Soc. Am. **20,** 35 (1930)] by H. B. Williams also deserves mention.

Applied Optics

Letters to the Editor

Letters to the Editor should be addressed to the Editor, APPLIED OPTICS, 1155 16th St., N.W., Washington 6, D.C.

Electro-Optic Effect of Gallium Arsenide

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Received 19 January 1963.

Cubic crystals in class 23 or $\bar{4}3m$ can exhibit a linear electro-optic effect with high degree of symmetry. The utility of such crystals as ZnS and CuCl for optical modulation has been described.[1,2] We have measured the electro-optic properties of the isostructural compound GaAs which transmits light in the infrared[3] and can be obtained with sufficiently high resistivity[4] to permit measurement of its electro-optic constant.

A crystal of "semi-insulating" gallium arsenide obtained from Merck & Co. was cut to form a rectangular bar 7 mm long with 4 mm square ends which were (111) faces and were polished. The sides were $(11\bar{2})$ and $(1\bar{1}0)$ faces. Indium electrodes were applied to the $(11\bar{2})$ faces, and a source of 2000-V peak ac at 900 kc/sec was connected to establish an electric field in the GaAs. The crystal was placed between crossed polarizers (Polaroid type HR) with axes at 45° to the field in a light beam obtained from a 100W Sylvania concentrated arc lamp with an interference filter. A light chopper was used to interrupt the beam which was then detected by a Kodak lead sulfide infrared photodetector.

The increase in chopped light level upon applying the field was noted, and after removing the field one polarizer was rotated from the crossed position by an angle θ until the same increase in light level was achieved. Measurements were made at 8 wavelengths between 1.0 and 1.7 μ.

For light traveling in the [111] direction in cubic crystals, the induced birefringence has axes along $[11\bar{2}]$ and $[1\bar{1}0]$ when the electric field is along $[11\bar{2}]$,[2] and

$$\Gamma = \frac{2\sqrt{2}/2\ \pi l n_0^3 r_{41} V}{\lambda d},$$

where Γ is the phase retardation, l is the light path, d is the distance between electrodes, V is the applied voltage, λ is the wavelength, n_0 is the index of refraction, and r_{41} is the electro-optic con-

stant. The average fraction of the light transmitted when the field is on is [5]

$$\frac{I}{I_0} = {}^1/_2[1 - J_0(\Gamma_{\text{peak}})],$$

where J_0 is the zeroeth order Bessel function, and when the polarizer is rotated the average fraction of light transmitted is

$$\frac{I}{I_0} = \sin^2\theta.$$

Using these relationships, the values of $n_0^3 r_{41}$ obtained at wavelengths between 1.0 and 1.7 μ were found to be between 5.5 and 6.3 $\times$ 10^{-6} cm/kV with no recognizable trend in the variation with wavelength. A second sample cut from the same crystal had $n_0^3 r_{41} = 9 \times 10^{-6}$ cm/kV. Further measurements on these crystals using dc or 60-cps fields in an appropriate optical configuration[1] gave lower values for $n_0^3 r_{41}$ (between 1.1 and 4.9 $\times$ 10^{-6} cm/kV). Such variable results are probably a result of the specimen conduction. Low-frequency field configurations are determined by the resistivity, electrode uniformity, and surface conductance, all of which can influence the results obtained. For this reason the results obtained at 900 kc/sec, where the field distribution is determined primarily by the dielectric constant, are considered to be more representative of this material.

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Simple Method for Photographic Photometry

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Received 11 January 1963.

Photographic photometry as normally carried out requires suitable control procedures. A typical control may be a strip of film which has previously been exposed in a known manner. If this control strip has been processed prior to use, the test sample must be processed in precisely the same way. If an unprocessed control strip is available, it must be shielded from the test exposure and then the two must be processed together and compared by means of a densitometer.

The purpose of this letter is to describe a simple method for rough photographic photometry which eliminates the need for (a) a separate control strip, (b) any but very loose control of processing, (c) a shield over the control area during the test exposure, and (d) a densitometer. The method provides a quantitative estimate of a fogging exposure that appears to be accurate within a factor of 2. Such a method might be useful for simple monitoring under conditions where controlled photographic photometry is not possible. In the tests to be described, all exposures were made with tungsten light. However, the principle could be adapted to other types of radiation that affect a photographic emulsion.

The method works on the principle that a fog exposure superimposed upon a faint primary exposure will obscure the primary image in the developed film. The desired quantification is provided by the circumstance that, the higher the fog level, the higher is the density of the primary image which is obscured. The reason is that a photographic emulsion responds logarithmically; a given exposure applied to a weakly preexposed area produces a greater increase in density than the same exposure applied to a strongly preexposed area.

The method thus uses merely a piece of film upon which a series of faint images has been preexposed. We have found that a suitable type of image consists of small alphabetical characters, since they are easily obscured. In our work we used Roman letters having a height (lower-case "e") of 0.6 mm. The text could convey a message relevant to the fog exposure that causes that particular section of the text to be the first one legible.

The exposure of the text is gradually increased through the series; this is conveniently done by printing a suitable original negative through a step tablet. In our work, we used Kodak Commercial Film (sheet), a power-of-two step tablet, and exposures of the order of 70 m-c-sec. Depending on the subsequent development, the resulting density of the preexposed text varied from about 2.0 downward to fog. After the exposure of the text, it is necessary to provide an over-all latensification flash. If this is not done, very low levels of the radiation subsequently to be monitored may themselves latensify and hence strengthen the primary image instead of obscuring it. The required latensification flash was found by trial to be about 0.003 of the primary exposure. This is insignificant compared with the other exposures involved.

The entire film sample, thus prepared, is then exposed to the radiation which it is desired to measure. After the film is processed, it is found that some of the faint preexposed text is no longer readable; the greater the fogging exposure, the higher are the levels of preexposure that are obscured.

In our tests, the fogging exposure was also applied through the

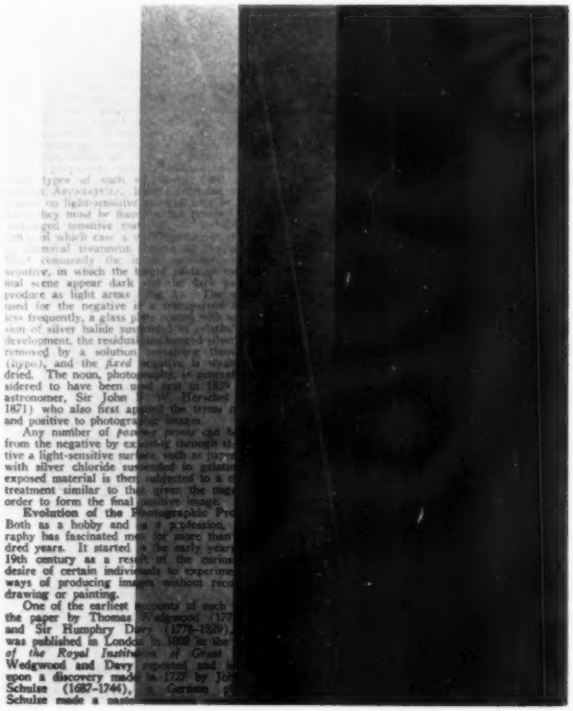

Fig. 1. Photometric test of the device. The stepped preexposure of the alphanumeric text increases downward, while the over-all fogging exposure steps increase to the right.

power-of-two step tablet, as shown in the illustration. Samples were processed in Kodak Developer DK-50, and it was found that the fog exposure which obscured a given level of text preexposure was equal to 10 times the text preexposure. This was true for any development time from 2 to 10 min. If film is prepared with known levels of preexposed text, therefore, the fogging exposure can be estimated quantitatively merely by processing the film and determining the last obscured step.

The relative insensitivity of this procedure to variations in development also suggests the use of monobath developers, which would simplify processing. If supplied in viscous form, as in a squeeze tube, the developer could be spread with the fingers, eliminating the need for any equipment other than a room that can be darkened.

The description of this procedure is for information only and is not to be construed as a recommendation or inducement to infringe patents, if any, of others.

The Detectivity of Cryogenic Bolometers

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Texas Instruments Incorporated, Dallas 22, Texas. F. J. Low is now at National Radio Astronomy Observatory, Greenbank, West Virginia.

Received 25 September 1962.

The performance characteristics of germanium bolometers operating below 4.2°K have been reported previously.[1] It was shown experimentally that the limiting source of noise in these bolometers is the temperature fluctuation caused by the random flow of heat between the sensing element and the heat sink. In certain cases, however, this noise may be less important than the noise generated by random fluctuations in the intensity of incident or reradiated radiation. The magnitude of this radiation noise is calculated for cases of practical interest.

It is convenient to summarize all major contributions to the noise in a bolometer by writing the square of the noise equivalent power,* N.E.P., as the sum of five independent terms:

$$(\text{N.E.P.})^2 = \frac{4kTR}{s^2} + 4kT^2G + 8\epsilon\sigma kAT^5 + 8\epsilon\sigma kAT_b^5 \sin^2\left(\frac{\phi}{2}\right) + \frac{Ci^\alpha}{f^\beta S^2}. \quad (1)$$

The first term is the square of the Johnson noise voltage across the bolometer of resistance R at temperature T, divided by the square of the responsivity, S. The Boltzmann constant is denoted by k. The second term is the square of the temperature noise power, where G† is the thermal conductance between the heat sink and sensing element. The third term arises from random fluctuations in the emission of the sensing element. This element, of area A, is assumed to radiate at all wavelengths with an average emissivity ϵ, and σ is the Stefan–Boltzmann constant. The fourth term represents the noise in the incident radiation originating from a blackbody background at temperature T_b. The detector is taken to be Lambertian, and the angle ϕ defines the size of the cone which accepts the background radiation. Furthermore, it is assumed that the emission and absorption of radiation are independent, that is, no stimulated emission is present. The last term is included to indicate the possibility of current noise of indefinite magnitude determined by the constant C. For our purposes we will exclude all excess noise from further consideration.

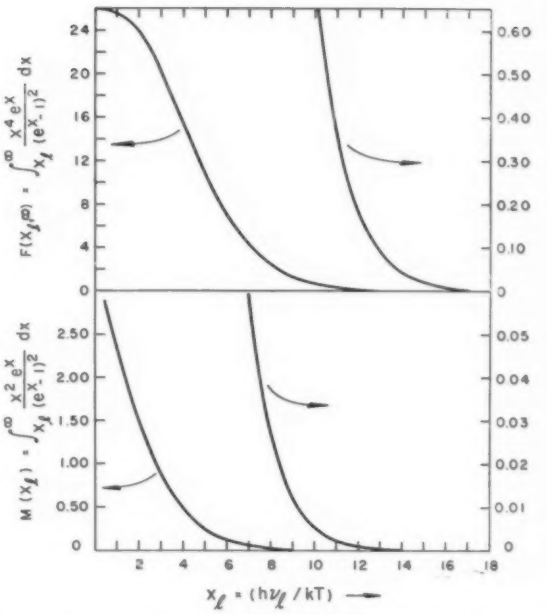

Fig. 1. $F(x_l, \infty)$ and $M(x_l)$ are both plotted as a function of x_l.

The term "ideal" bolometer refers to that case where S is very large and G is very small, leaving only the third and fourth terms of Eq. (1) as significant. In practice, however, the thermal conductance is never made negligibly small, so that the second term is always larger than the third and fourth terms when T is comparable to T_b. When T is much lower than T_b the third term vanishes and the background radiation noise can become dominant. We prefer the expression "perfect" bolometer for this latter case since the radiation power is carried away to the heat sink by a noiseless conductive heat current,* introducing no additional noise and leaving only the inherent temperature noise of the bolometer and the background radiation noise.

Using the results derived previously for the particular case of the germanium bolometer,[1] an approximate expression may be written for the N.E.P. of a nearly "perfect" bolometer†:

$$(\text{N.E.P.})^2 = 16kT^2G + 8\epsilon\sigma kAT_b^5 \sin^2\left(\frac{\phi}{2}\right). \quad (2)$$

Examination of this equation shows the conditions which are necessary for the two terms on the right to be of equal magnitude. The optimum bias power, P, has been shown[1] to be 0.1 TG, whereas the total radiation power, Q, is $\epsilon\sigma AT_b^4 \sin^2\phi/2$. Therefore Eq. (2) may be written as,

$$(\text{N.E.P.})^2 = 8kT\left[20P + \left(\frac{T_b}{T}\right)Q\right]. \quad (3)$$

* In the definition of N.E.P. and throughout this paper, we take the post-detection bandwidth to be unity.

† G refers to the flow of heat from the element strictly by conduction.

* The assumption here is that temperature noise is independent of the magnitude of the conductive heat current producing the temperature gradient between the sensing element and the heat sink.

† This result assumes that the temperature of the sensing element is only slightly greater than that of the heat sink. This is certainly true in most practical cases.

For cases of practical interest, (T_b/T) may be 100, and the bolometer becomes background limited when Q exceeds $P/5$.

Up to now we have only considered a flat spectral response for the bolometer. In practice, it is usually necessary to limit the spectral bandwidth by means of cooled filters. Assuming ideal filters, we will calculate the variation of specific detectivity, D^*, for a "perfect" thermal detector as a function of both short and long wavelength cutoffs, λ_s and λ_l, respectively.

Following Lewis[2] and Fellgett,[3] we may write the exact expression for the noise associated with the radiation power received by the bolometer:

$$(\text{N.E.P.})^2 = \frac{4\pi A\epsilon(kT_b)^5 \sin^2\left(\frac{\phi}{2}\right)}{c^2h^3}\int_{x_l}^{x_s}\frac{x^4e^x}{(e^x-1)^2}\,dx, \quad (4)$$

where $x \equiv (hc/\lambda kT_b)$. For a hemispherical field of view the specific detectivity is

$$D^*(x_l, x_s) \equiv \frac{A^{1/2}}{\text{N.E.P.}} = 2.04 \times 10^{17}[\epsilon T_b{}^5 F(x_l, x_s)]^{-1/2}\left(\frac{\text{cm} - \text{cps}^{1/2}}{\text{watt}}\right), \quad (5)$$

where

$$Fx_l,(x_s) = \int_{x_l}^{x_s}\frac{x^4e^x}{(e^x-1)^2}\,dx.*$$

A plot of $F(x_l, \infty)$ is shown in Fig. 1. For arbitrary x_s and x_l, we may write $F(x_l, x_s) = F(x_l, \infty) - F(x_s, \infty)$.

The corresponding expression for a perfect photoconductor[3] is

$$D^*(x_l) = 3.00 \times 10^{25}[\epsilon\nu_l{}^2T_b{}^3M(x_l)]^{-1/2}\left(\frac{\text{cm} - \text{cps}^{1/2}}{\text{watt}}\right), \quad (6)$$

where $\nu_l = c/\lambda_l$, and

$$M(x_l) = \int_{x_l}^{\infty}\frac{x^3e^x}{(e^x-1)^2}\,dx.$$

A plot of this function is also shown in Fig. 1. In Fig. 2 we present a plot of D^* for a "perfect" cryogenic bolometer as a function of both short and long wavelength cutoffs, λ_s and λ_l.† The well-known curve for a perfect photoconductive detector as a function of long wave cutoff is included for comparison. The horizontal lines for a "perfect" bolometer with no cutoffs and an "ideal" 300°K bolometer are also included for comparison.

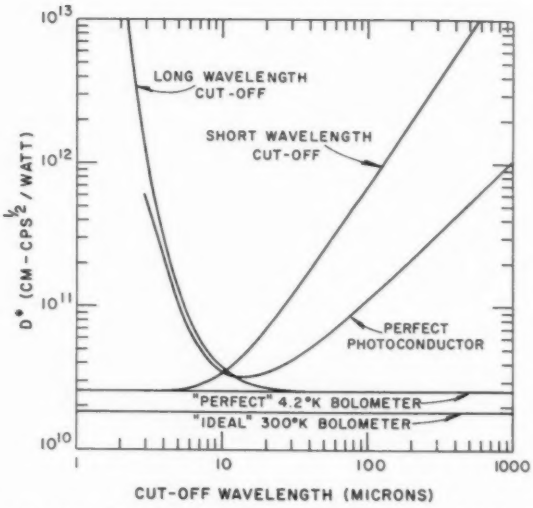

Fig. 2. The detectivity of a "perfect" bolometer is plotted as a function of both short and long wavelength cutoffs. Plots for a perfect photoconductor and two other cases are included for comparison. The background temperature is 300°K.

An example of increasing interest is that of a cryogenic bolometer operating at long wavelengths. For this case, the Rayleigh–Jeans approximation holds, and Eq. (5) reduces to

$$D_{R-J}{}^*(x_l, x_s) = 2.04 \times 10^{17}(\epsilon T_b{}^2)^{-1/2}\left[\frac{\lambda_s{}^3}{1-(\lambda_s/\lambda_l)^3}\right]^{1/2}\left(\frac{\text{cm} = \text{cps}^{1/2}}{\text{watt}}\right). \quad (7)$$

As λ_l/λ_s becomes large the power removed by the long wavelength filter becomes very small and the detectivity is independent of λ_l. On the other hand, large values of D^* are made possible by the use of cooled narrow-band filters, for which $\lambda_s/\lambda_l \cong 1$.

Finally, the variation of D^* with background temperature, T_b, can be shown to be identical for photoconductive and thermal detectors in the Rayleigh–Jeans limit. This is not the case at shorter wavelengths.

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* The transport integrals used here are conveniently tabulated in Natl. Bur. Std. (U.S.), Circ. No. 595.

† ϵ is assumed to be 1.

D. L. MacAdam, 1962 President of OSA, awards the first Mees Medal to A. Kastler, Ecole Normale Superieure, during the OSA 47th Annual Meeting, while the 1963 OSA President, Stanley S. Ballard, reflects.

Applied Optics Patents

3,021,752 20 Feb. 1962 (Cl. 88-32)
Image stabilizer and dimmer for optical devices.
R. Avery. Filed 23 Oct. 1959.

The "image stabilizer" consists of a rotating sector plate which has 24 slots cut out, each 2° wide, and which is driven at a speed of about 120 rpm. If this sector plate is placed close to the eyepiece of a telescope, the image of, say, a twinkling star seen through the telescope is periodically interrupted. However, the visual impression perceived by the retina of the eye will persist for short periods, and the distracting effects of the twinkling and poor seeing are claimed to be greatly reduced. J.R. M-A.

3,022,706 27 Feb. 1962 (Cl. 88-24)
Portable photogrammetric rectifier.
G. Kargi. Assigned to the U.S.A. as represented by the Secretary of the Army. Filed 18 June 1958.

A photogrammetric rectifier is used in correcting aerial negatives for image displacement due to lens aberration, plane tilt, swing, crabbing, correction of terrain height, and other errors in the negative, in order that pictorial information of the negatives may be translated into the various forms of maps as required. This patent involves construction details of such a rectifier intended for field use, embodying many features to simplify its use and to improve accuracy. D.E.W.

3,034,890 15 May 1962 (Cl. 96-3)
Color formation.
E. H. Land. Assigned to Polaroid Corporation. Filed 31 May 1955.

Describes a multilayer diffusion transfer system for producing a reflection print composed of a pair of superimposed images. A red positive image records cool-color information, while a gray positive image records warm-color information. It is claimed that "they combine to present a multicolored composite image of surprising spectral range" which is "satisfactory for particular situations." Five claims cover the details of the diffusion transfer processes involved. C.S.McC.

3,035,492 22 May 1962 (Cl. 88-61)
Electronic control of optical and near-optical radiation.
R. Blythe. Filed 15 May 1959 (divided—original application filed 23 May 1952).

Describes an arrangement for the control of optical and near-optical radiation by means of a magneto-strictive element, the basic idea of which is the variation of the distance between a reflecting element and a fixed semitransparent film. (The principles described have a wide range of application in many fields, especially in instrumentation and metrology.) A.E.M.

3,036,493 29 May 1962 (Cl. 88-14)
Optical positioning system.
A. Mottu, H. Hassmann, and C. Koechlin. Societé Genevoise de Instruments de Physique. Filed 27 Jan. 1959 (in Switzerland 14 Feb. 1958).

By this method, the table of a jig borer is accurately positioned by optical reference to a scale on the table graduated in millimeters. Fractional millimeters are obtained by moving the index the required amount. Where settings must be repeated, as with multiple workpieces, adjustable stops on the carriage holding the index may be set so that the fractional dimensions are quickly obtained. D.E.W.

3,036,496 29 May 1962 (Cl. 88-24)
Apparatus for projecting multiple superimposed images.
C. M. Frederick, Jr., and G. V. Frederick. Filed 26 Feb. 1959.

Multiple projectors are arranged to present fixed or movable superimposed images for use as background material in commercial television programming. Through the clearing or opaquing of areas, the images are made to seem to pass over or behind each other. Optical alignment to prevent distortion is described. D.E.W.

3,038,082 5 June 1962 (Cl. 250-220)
Photometric device.
M. Biermann. Assigned to Continental Elektroindustrie A.G. Filed 18 Aug. 1960 (in Germany 20 Aug. 1959).

In a class of photometric devices for determining the relative intensity of two beams of light which are alternately and periodically conducted to a single detector, wherein a synchronous auxiliary signal is commonly employed as a comparison, three electro-optical methods for improving the synchronism of the auxiliary signal are described. R.D.A.

3,039,349 19 June 1962 (Cl. 88-1)
Optical device having light-filtering means.
T. E. Rodgers. Assigned to Northrop Corporation. Filed 19 Oct. 1959.

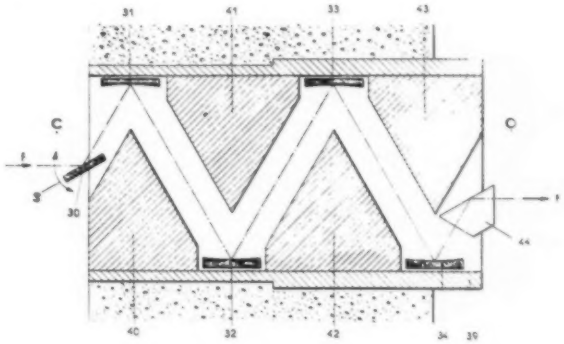
Describes a method of reducing internal reflections in a specified optical system with a high degree of efficiency. The basic considerations are applying coating with absorbing agents and having a very close match to the index of the optical element. An overcoat of the same formulation, with finely divided lampblack, provides for highly efficient attenuation. Internally reflected images of the sun are said to have been reduced by a factor of 10^6. A.E.M.

3,039,358 19 June 1962 (Cl. 88-29)
Means for presenting stereo pictures for viewing.
O. Vierling. Assigned to Zeiss Ikon A.G. Filed 29 Dec. 1959 (in Germany 26 Feb. 1955).

The invention relates to apparatus for projecting or viewing stereo pictures which have been produced by a photographic camera having a single lens system. The construction is particularly designed to overcome not only the trapezoidal distortion claimed to be produced on the boundary lines but also all other objects within the field of view. A rectifying lens is arranged adjacent to the stereo pair during projection, and the disturbing distortion of the boundary may be compensated by means of a mask. D.E.W.

3,041,916 3 July 1962 (Cl. 88-1)
Afocal optical device having a mounting providing protection against dangerous radiation.
S. Clavé and M. Clavé. Filed 11 Mar. 1960 (in France 13 Mar. 1959).

Optical devices for looking into "hot" cells are likely to suffer damage due to the darkening effect of the radiation on refractive optics. The device described uses only reflective optics in which cylindrical mirrors 31, 32 33, and 34 transmit the image while dangerous radiation is blocked by intervening shielding material. The spacing of the mirrors is according to the formula $\frac{1}{2}(R_1 + R_2)\cos i$, where R_1 and R_2 are the radii of curvature, and i is common angle of incidence. A pivotally mounted plane mirror permits scanning to increase the field of view. D.E.W.



3,041,921 3 July 1962 (Cl. 88-14)
Polarimeter apparatus.
E. G. Pickels and G. K. Turner. Assigned to Beckman Instruments, Inc. Filed 17 Nov. 1958.

Describes photoelectric polarimeters, using a mechanically oscillating polarizer to generate an error signal whose phase and magnitude indicate the error, and electronic techniques to remove the error and display the rotation nduced by the sample. W.L.H.

3,043,709 10 July 1962 (Cl. 117-7)
Organic polymeric structure having an ultraviolet-light absorbent compound incorporated therein.
L. E. Amborski. Assigned to E. I. du Pont de Nemours and Company. Filed 18 July 1958.

Described is the formulation of organic polymeric structures suitable for use in films. The principal feature is the inclusion of an ultraviolet-absorbing compound, concentrated near the surface so that degradation and consequent peeling caused by sunlight is eliminated. The ultraviolet absorber meets the requirements of having high absorption capacity, adequate dissipation of absorbed energy, and resistance to action of water, and is free of odor and color. A.E.M.

3,043,710 10 July 1962 (Cl. 117-33.5)
Fluorescent screens.
S. H. Patten and A. R. Kunes. Assigned to E. I. du Pont de Nemours and Company. Filed 20 Feb. 1959.

Described is the process for making improved fluorescent and intensifying screens that are dimensionably stable, do not color with aging, and have good adhesion between layers. A.E.M.

3,043,956 10 July 1962 (Cl. 250-83.3)
Measuring systems using infrared radiation.
M. J. Cohen. Assigned to Franklin Systems, Inc. Filed 24 Sept. 1958.

Describes a variety of novel systems for measuring the thickness and other properties (molecular relaxation times, internal energy transfer, semicon-

ductor impurities, internal flaws, etc.) of solid or fluid materials, based upon determination of the phase shift in radiation detected from such material, with reference to the modulation of incident infrared radiation. The method is independent of fluctuations in source amplitude or emissivity properties of the material under test, thereby permitting new types of measurements while older types are rendered simpler and more accurate. R.D.A.

3,047,410 31 July 1962 (Cl. 106-53)
Glass composition.
E. L. Woodall and G. E. Reinker. Assigned to General Electric Company. Filed 13 Apr. 1961.

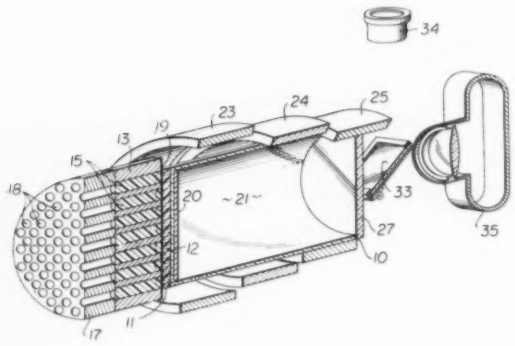
The composition of a lithia-free soft glass having high electrical resistance and suitable for use in the production of envelopes and other parts of electrical devices, such as electronic-discharge tubes, electric lamps and the like, is described. The properties of the new glass are compared with those of a similar glass containing lithia:

	new glass	lithia glass
Density	3.83	3.994
Strain point °C	413	406
Annealing point °C	450	443
Softening point °C	603	595
Electrical resistivity, log 10 ohm-cm at 350°C	9.5	9.4
Electrical resistivity, log 10 ohm-cm at 300°C	10.6	10.4
Electrical resistivity, log 10 ohm-cm at 250°C	11.7	11.4
Coefficient of thermal expansion (0–300°C) times (10^7) per °C	88	88

G.W.C.

3,048,698 7 Aug. 1962 (Cl. 250-71.5)
Scintillation camera.
R. W. Carlson. Assigned to Picker X-Ray Corporation. Filed 11 Mar. 1959.

This scintillation camera is capable of producing a "picture" of the gamma-ray emission from body organs during tracer studies, without the disadvantages of scanning techniques. A lead collimator (18) is followed by a scintillation grid whose holes, in alignment with those of the collimator, are filled with scintillation crystal material. An optical density filter (19) corrects for non-uniformities in the sensitivity of the crystals; the light then falls on the photo cathode of image tube (10). D.E.W.



3,048,699 7 Aug. 1962 (Cl. 250-83.3)
Method and apparatus for measuring absorption spectra.
S. A. Francis. Assigned to Texaco, Inc. Filed 15 May 1958.

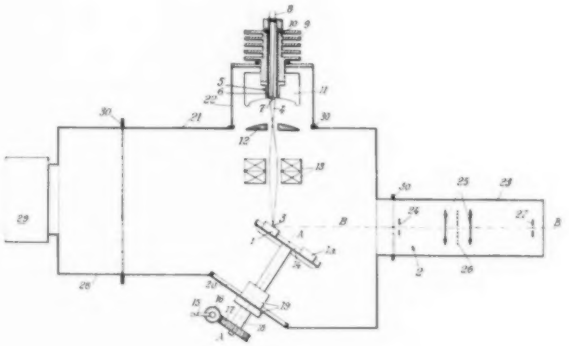
Methods for measuring the infrared absorption spectrum of thin films and a double-beam chopper sector with beveled radial edges that do not obscure the reference beam are described. In double-beam measurements, the sample beam makes four or five reflections with parallel mirrors coated with the sample. Uncoated mirrors are used in the reference beam. The single-beam method is to modulate the radiation with a rotating circular mirror, half of which is coated with sample. The use of a polarizer to enhance the contrast of the absorption spectra is covered. T.K.M.

3,049,047 14 Aug. 1962 (Cl. 88-14)
Method for analyzing microscopic particles and the like.
M. I. Polanyi, J. E. Johnston, and M. G. Brown. Assigned to American Optical Company. Filed 5 Dec. 1960. Div. of application filed 3 Apr. 1957; now patent number 2,969,708.

This invention relates to a convenient, rapid, and dependable method of determining the distribution of cell diameters in a blood specimen. Permanent graphs indicative of blood-cell volume and refraction index may be obtained by this invention, which utilizes a focused beam of monochromatic light and an annular aperture to transmit only energy scattered by individual cells. Means are provided to transport the blood sample along the axis of the optical system, whereby a focused pinhole effectively scans the medium. A photocell detects the energy, and the electrical output is recorded. D.J.L.

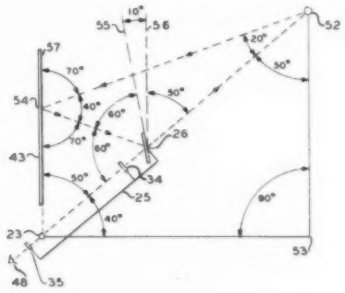
3,049,618 14 Aug. 1962 (Cl. 250-49.5)
Methods and devices for performing spectrum analysis, in particular in the far ultraviolet.
P. Thomé. Assigned to Commissariat à l'Energie Atomique. Filed 4 May 1960 (in France 13 May 1959).

In a vacuum chamber, an electron gun and lens (13) focuses an intense beam of electrons upon a sample (3) that is to be analyzed for its atomic constituents. Local melting of the sample is accomplished, and the resulting radiation of the visible and ultraviolet is analyzed by means of a spectrometer disposed along the axis BD. Several samples can be inserted into the vacuum chamber at one time and selected by means of the rotating turret, or a single sample can be moved about so that local variations in its composition can be studied. The area of the spot can be, for instance, 0.01 sq. mm, and the electron beam can be pulsed to obtain very high local temperature without heating the surrounding area by conduction. Analysis of low atomic numbers, such as carbon, sulfur, and phosphorous, and gases, such as oxygen, nitrogen, and halogens, is possible. D.E.W.



3,049,963 21 Aug. 1962 (Cl. 88-2.4)
Optical instrument in the nature of a surveying transit.
M. W. Parsons, Jr. Filed 30 June 1959.

Horizontal pivot (23) is located on a platform which can be leveled and oriented for azimuth measurements. Vertically above 23 is a large mirror (57). Pivotally mounted on 23 is an arm (25) carrying sighting rings (35) and (34) and a second smaller mirror horizontally rotatable on a pivot (26). When an object (52) is sighted and aligned both by direct vision and reflection through the mirrors as shown, the resulting triangles can be solved to give both the distance of the object and its height above the ground point (53). D.E.W.



3,049,970 21 Aug. 1962 (Cl. 88-24)
Lens adapter.
O. L. Steinberg. Filed 29 June 1959.

When photographing for reproduction purposes a picture that has been reproduced already by the ink printing process, the patterns of the two screens will produce a moiré effect, which will spoil the reproduction. This patent describes an attachment for the copying camera lens which oscillates a tilted plane-parallel glass plate by means of a motor in such a way as to break up the dot pattern of the picture being copied. D.E.W.

3,051,035 28 Aug. 1962 (Cl. 88-1)
Flexible pyroscopes.
A. A. Root. Assigned to American Optical Company. Filed 17 May 1960.

Describes special fiber optics bundles adapted for the measurement of the temperature of hot objects by remote measurements on their radiation. W.L.H.

Optics—an Action Program

This statement was prepared by Van Zandt Williams with cooperation from members of the Task Force and has been approved officially by the Board of Directors of the Optical Society of America.

Summary

The Board of Directors of the Optical Society of America is properly concerned with the scientific state of health of optics in the United States. During the last year, a study of this problem has been made and a program of corrective action has been proposed. This article presents the background of this study, its summary findings, the proposed action program, and the people who will lead it. The persons concerned with this project, both past and future, want to thank members of the scientific community who give aid.

Needs in Optics

During the last few years, there has come a seeming contradiction in the field of optics. Simultaneously, there are indications of a de-emphasis of optics in academic teaching and research together and a tremendous increase in the application of optics and a consequent shortage of personnel with training in optics.

Optics people have shared this concern and at the Fall 1961 Meeting of the OSA, two proposals for optics programs were submitted to the Board of the Society. At the Spring 1962 Meeting of the OSA, the Board formed an *ad hoc* committee with the following charge:

> . . . to consider the problem of current needs in optics teaching and research and present a definite plan of action to the Board at its meeting in October 1962.

The Committee was specifically charged to consider the two proposals that had been submitted to the OSA Board of Directors on 16 October 1961. These two proposals were:

> 1. *The "Boston Proposal":* A description of a proposed National Institute of Modern Optics and a program to determine its need and feasibility.
> 2. *The "Rochester Proposal":* Recommendations were—that the Optical Society conduct a survey to determine the extent and the nature of the national demand for persons trained in optics, and the nation's present capability to meet this demand; and that, when the preliminary results of the survey are available, a meeting of the Society be convened in Rochester, New York, for the presentation and discussion of the survey results.

The membership of the Needs in Optics Committee was:

Ex Officio, Mary E. Warga	S. S. Ballard
Ex Officio, D. L. MacAdam	W. R. Brode
Chairman, V. Z. Williams	H. S. Stewart

This Committee submitted its report to the OSA Board on 2 October 1962. The report, with its recommendations, was accepted by the Board and the Committee was discharged.

Summary of Report—Area of Study, Findings, and Recommendations

The whole question of optics is made complex by its diffuse nature. Optics is both a scientific field in itself and an interdisciplinary aspect of larger fields such as physics, engineering, chemistry, and physiology. This diffuseness causes problems in communications; e.g., many people use the term "optics" in a broad sense but impose mental restrictions when it is used in a phrase such as "Research in Optics" or "Education in Optics". This study attempts some clarification by using the word "optics" in its broadest or umbrella definition [*J. Opt. Soc. Am.* **51**, 1042 (1961)]:

> *Optics:* The science which deals with radiant energy, its genesis, its propagation, the effects which it suffers, the effects which it produces, and all phenomena closely associated with it.

and the phrase "optics *per se*" for the narrower definition as given in the AIP booklet, *Glossary of Terms—Optics and Spectroscopy:*

> *Optics:* A combination of the physical and mathematical sciences that pertain to the nature, properties, and control of electromagnetic radiation and to the phenomena of vision.

The study and action here discussed deal with the broader area of optics.

Findings

During this century, optics *per se* has matured as a discipline of physics and in very recent years has suffered the consequences of maturation. Basic research has fallen off in favor of more glamorous fields, and optics *per se* education in the undergraduate area has become inadequate. Research has its faddish aspects; a research field tends to seed or unseed itself at too rapid a pace.

Over this same period, there has been a steady increase in the application of optics, but, until very recently, these application requirements have not noticeably exceeded the rate of supply of people with optics training or the rate at which scientists could be converted to areas of optical need.

Today this balance no longer holds, as anyone seeking manpower with optics knowledge can testify. For example, in 1960, of the 20,500 employed physicists, 7.8%, or about 1600, regis-

tered as working in optics. As of June 1962, of 7000 graduate students in physics, only 1.5%, or about 100, were working in optics.

The study has shown that a conservative estimate of the requirement for new people trained in optics in the next five years is 3500, whereas the estimated supply is only about 25% of that number. A large portion of this requirement is in the engineering rather than the research area.

It is therefore evident that there is a serious imbalance in supply and demand of optics training in this country. While an exact balance cannot be expected, it is required that the supply not fall below a hard-core competence on which growth and exploitation can be built. Such a hard-core competence must come from the academic area, but universities will change academic emphasis very slowly to meet this need. Any constructive influence that can be exerted here will help.

The Optical Society of America has responsibility to take active leadership to meet today's needs in optics—the maintenance of basic optics research, the extension of optics technology, the increase of personnel trained in optics and, above all, the overhaul of education in optics to supply suitable course material and student inspiration. In such a diffuse and complex situation, there is no single, simple program which can meet such needs: it is necessary that several areas and programs be pursued simultaneously. These may not all be equally successful or effective, yet effort on all must be made.

Recommendations

The Needs in Optics report broke the wide area of optics into coherent subareas where status improvement seemed desirable. It recommended that a competent individual be asked to head each subarea, make a careful consideration of the situation, and submit a program by which such improvement could be achieved. These action areas, the Task Programs, and the Task Leaders are given below.

With respect to the particular charges to the study committee, it is felt that the present study and action programs are the equivalent of the "Rochester Proposal". The area of the "Boston Proposal" is one of the proposed Tasks.

Action Areas, Tasks, and Leaders

The single theme of the whole action program is to increase the national supply of personnel trained in optics. The area most contributive of both science and desired personnel is university graduate research—be it physics, engineering, chemistry, or physiology. Of the six proposed Tasks, three are so aimed.

In order that graduate research programs in optics can be successfully maintained, it is necessary that there be a supply of undergraduates with both basic education and interest in optics. Two of the six Tasks are so aimed.

In addition to university training, there is need of opticians, personnel who work optical materials, and technicians to support any research and engineering area. One Task is devoted to this purpose.

Graduate Research Programs—Tasks I, II, and III

These three Tasks are separately aimed, but, because of the diffuse nature of optics, it is inevitable that there be some overlap at the interfaces. It is felt that such overlap can be valuable since two different approaches provide better probability of success.

Task I. Research in Optics per se

Leader

Stanley S. Ballard, Chairman, Department of Physics, University of Florida, Gainesville, Florida.

Purpose

The "Boston Proposal" was a subject of careful study and discussion. It was concluded that the Proposal was a very thoroughly considered effort, but there was not a sufficient ground swell of interest by the optical scientists in the U.S.A. today to make it a viable proposition. The reasons for this were various, but the one of primary concern was a lack of agreement with the basic assumption of the "Boston Proposal": that optics (and particularly optics *per se*) research in the United States is in a parlous state, both absolutely and with respect to European status. It is desirable that this assumption be checked, and a sponsored conference of top optical scientists has been suggested for this purpose.

Such a conference would have added benefit for the OSA in defining the various areas of optics and the relation of those areas to other research fields, as well as providing a projection of future directions of efforts in optics.

Program

A sponsored conference of major optics researchers will be planned at some "central" location such as Washington, D.C. The agenda will be simple and straightforward: What basic (chiefly theoretical) research is now going on? Is it adequately supported? Would a substantial increment in support be advisable? Can the over-all program be expanded and, if so, how? Are there new areas opening up which should be explored? Is some kind of central organization needed for coordination purposes (the National Institute of Modern Optics of the "Boston Proposal")? It is planned that this conference be conducted by the Spring of 1964. A further program can be developed as the conclusions are obtained and analyzed.

Task II. Research and Graduate Training in Optical Engineering

Leader

Robert E. Hopkins, Director, Institute of Optics, University of Rochester, Rochester, New York.

Purpose

The single greatest need of "personnel trained in optics" is in the engineering area. Advanced systems for reconnaissance, metrology, or OAO experiments require a combination of mechanical, electronic, and optical systems competence that is not being trained in universities. This, as well as optical element material, design, and fabrication, has been relinquished by physics to engineering, but engineering departments are generally not aware of this new responsibility. It is the aim of this Task to get several leading engineering colleges or departments to include optics as an important element in their curriculum.

Program

To prepare material for a Summer Institute to present to representatives of engineering college departments the areas of engineering responsibility for optics, as well as curricula and research programs for carrying out that responsibility; to in-

terest engineering colleges in sending representatives to such an Institute; and to work through OSA to get financial support for such an Institute for the Summer of 1964.

Task III. Basic Long-Range Research Programs in Optics

Leader

Henry M. O'Bryan, Scientific Assistant to Vice President/Engineering & Research, The Bendix Corporation, Washington, D.C.

Purpose

This Task is aimed at areas of research which extend beyond Tasks I and II. The primary study revealed that certain areas of optics are subject to intensive application and exploitation by government agencies far out of proportion to the basic, continuing academic research in these areas. Current examples are spectroscopy, lasers, radiometry, and infrared instrumentation. It is essential to select and describe those scientific areas which will become of future interest and in which knowledge will be most valuable to rapid advancement in technology and engineering.

Program

The first step is to study the current and future requirements of government agencies and of industry. This information will then be used as a starting point to prepare descriptions of a number of fields in which research investigations will be most productive.

Following this, the more promising areas will be outlined and described in order to focus effort and to encourage their support, as well as to train more competent scientists.

Undergraduate Programs. Tasks IV and V

Again, these two Tasks have the common goal of stimulating the undergraduate, but different approaches are used.

Task IV. Undergraduate Research Programs

Leader

Jack H. Taylor, Department of Physics, Southwestern at Memphis, Memphis, Tennessee.

Purpose

A need of the long-range graduate research programs of Tasks I, II, and III is the availability of baccalaureate students with interest in optics. It is believed that optics is an ideal area for small college undergraduate research or advanced projects because of the simplicity and availability of equipment and the wide range of problems. An example is Southwestern at Memphis (prescat student body about 800). In six years, it has turned out 21 physics majors; 19 have gone on to graduate work, and 3 of these graduates will be working in optics.

It is the purpose of this Task to get equivalent programs going at other colleges.

Program

It is intended to associate a group of schools which would wish to set up equivalent programs. The requirements for such efforts will be determined; e.g., a list of research problems, updating professorial knowledge and interest, or funds and equipments. These problems can be handled by tapping the ideas of the 2000 present researchers in optics, by summer institutes, or by aiding in seeking grants for pooled requirements.

The participant group could be established by the Fall of 1963 and the academic year 1963–64 devoted to trial programs, coordination efforts with government and industrial laboratories, and fund applications, so that a full program would be established and operating beginning in September 1964.

Task V. Education in Optics

Leader

Mary E. Warga, Executive Secretary, Optical Society of America, Washington 36, D.C.

Purpose

The study revealed a general dissatisfaction with undergraduate teaching of optics in college physics departments. The classicists maintain that not enough optics teaching is required. Another group urges that new areas must be emphasized at the expense of optics courses. There are comments that "geometric optics is now an engineering and not a physics responsibility" and "optics is the most powerful tool in physics research, but this is not reflected in optics courses".

It is evident that the teaching of optics must be reconsidered in the light of present needs in physics and engineering. These needs must be determined and new course material proposed if the needs warrant.

Program

1. Obtain statistics available from past studies in this area by the American Institute of Physics, the American Association of Physics Teachers, the National Science Foundation, and the Commission on College Physics.
2. Ascertain the history and trends of education in optics. Determine the extent to which optics may have disappeared from one course in the physics curriculum only to appear in another or in chemistry, engineering, or physiology.
3. Extend these studies to reach a recommendation for changes in the teaching of optics, if it is found that these are needed.
4. Complete the publication and distribution of the pamphlet *Careers in Optics* during the 1963–64 academic year.
5. Coordinate this effort with that of the other Task Forces and with the International Commission for Optics' effort to study the teaching of optics now being made overseas.

Task VI. Training of Opticians and Optical Technicians

Leader

R. R. Brooks, Director of Manufacturing, Electro-Optical Division, The Perkin-Elmer Corporation, Norwalk, Connecticut.

Purpose

The "Rochester Proposal" concerned the problems of demand and supply of people trained at all levels. The primary need and the level at which OSA is best equipped to work is that of the optical scientist of college training. The optician and the technician are primarily an industrial requirement, trained by industry, the trade school, or the two-year technical institute. It is the intent of this Task to identify the demand and supply

aspects for opticians and technicians, to promote industrial support for training, and to provide course materials for schools, institutes, and in-house training.

Program

The program is in two parts. It is necessary that a compilation be made of the best of U.S. and foreign methods for classifying and developing skills through both in-house training and vocational schooling. Simultaneously, a "trade association" relationship in industry will be developed through an agency such as the American Ordnance Association to ascertain needs of specific industries and programs to alleviate them.

The study and initiation aspects will require six months and test programs an additional year. Permanent programs would be ready in late 1964 or 1965.

Task Force Leadership and Coordination

Leader

Van Zandt Williams, Vice President/Technical Development, The Perkin-Elmer Corporation, Norwalk, Connecticut.

Van Zandt Williams will act directly with this group to encourage and aid in programs. It is obvious that there will be some areas of overlap and mutual interest between these Tasks which will require coordination. Further, OSA should coordinate its program with interests of agencies such as the American Institute of Physics, and the American Chemical Society.

Because of the importance of this effort to the Optical Society of America, John A. Sanderson, a member of both the Board of Directors and the Executive Committee of the Board, has been designated as representative of the Board for cognizance of this program with V. Z. Williams.

photo D. L. MacAdam

Burt Carroll, Mary Corning *NSF*, and G. Wyszecki *National Research Council of Canada* in Rochester October 1962.

Emil Wolf, who was awarded, with L. Mandel, the prize for the best paper published in *J. Opt. Soc. Am.* in 1961, and K. Ogle, Chairman of the awarding committee.

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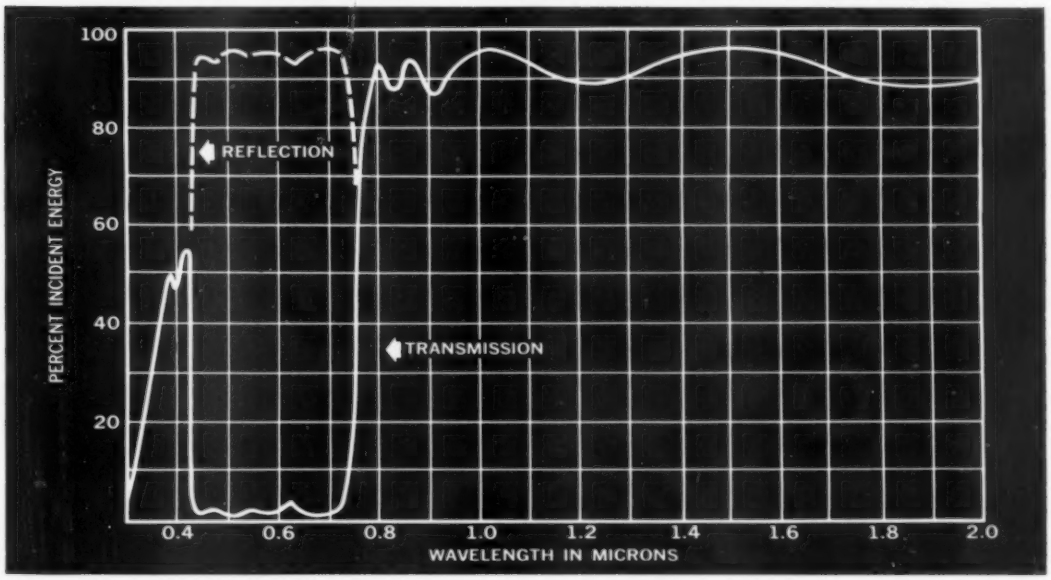

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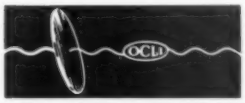

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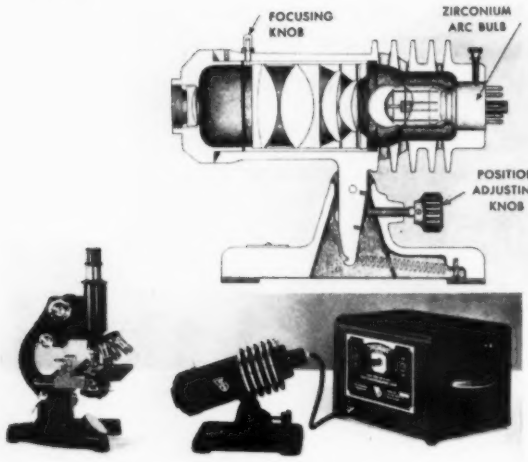

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The Condenser System

The condenser system of 7 optical elements is of extremely short focal length—only 16.5 mm—essential to use the point source of light to fullest advantage. Lenses are coated to minimize loss of light by stray reflection.

The Optical System

The optical system is mounted in a barrel which slides back and forth for focusing within the external housing—ventilated for heat dissipation. A detachable lens for high-power microscopy increases focal length, concentrating the light into a long, narrow beam. Light beam is aimed upon the microscope mirror by means of a non-slip adjusting screw, which controls angle of beam with the horizontal.

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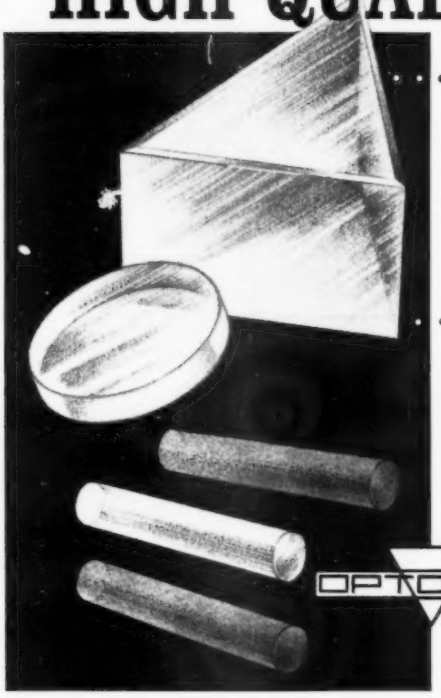

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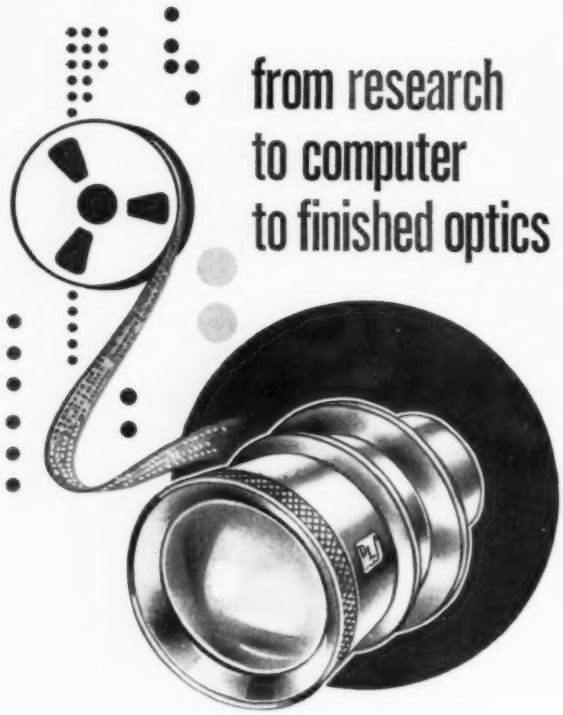

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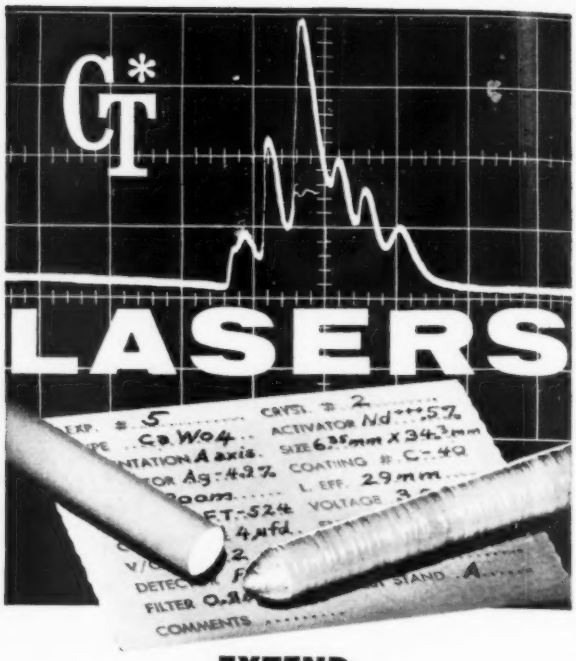

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Each issue will specially feature one area of applied optics in addition to the usual contributed papers, shop and technical notes, reports of meetings, Letters to the Editor, book reviews, Meetings Calendar, and special columns. The feature subject of each issue is the responsibility of the named editor.

1963		
July	**Atomic Spectroscopy**	M. E. Warga
August	**Masers**	—
September	**Spectroscopic Instrumentation**	—
October	**Bubble Chamber Optics**	S. Rosin
November	**Coblentz Commemoration**	E. K. Plyler
December	**Lens Design and Computers**	D. P. Feder
1964		
January	**Optics of the Photographic System**	G. C. Higgins
February	**Atmospheric Optics**	D. Q. Wark
March	**Chemical Optics**	M. K. Wilson
April	**Visibility**	S. Q. Duntley
May	**Microscopy**	J. R. Benford
June	**Fiber Optics**	C. W. Peters
July	**Optics in Japan**	R. A. Oetjen
November	**High-Speed Photography**	—
December	**Solar Optics**	G. Newkirk, Jr.
1965		
January	**Biophysics**	P. O'B. Montgomery
February	**Plasma Radiation**	L. M. Branscomb
April	**Optical Processing of Information**	G. W. King
May	**Optics and Microwaves**	G. Stroke
June	**Detectors**	R. A. Smith

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These reporters submit information from which are compiled in part the news columns of *APPLIED OPTICS*. They have a rather thankless and seldom properly recognized task, and the *APPLIED OPTICS* editors are very grateful to them.

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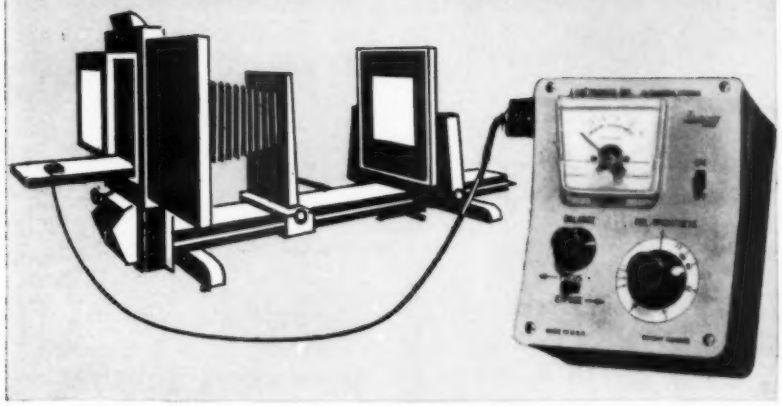

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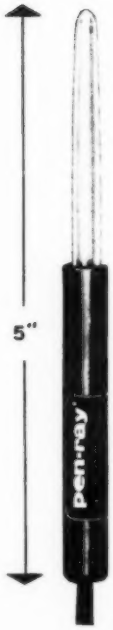

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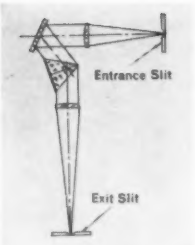

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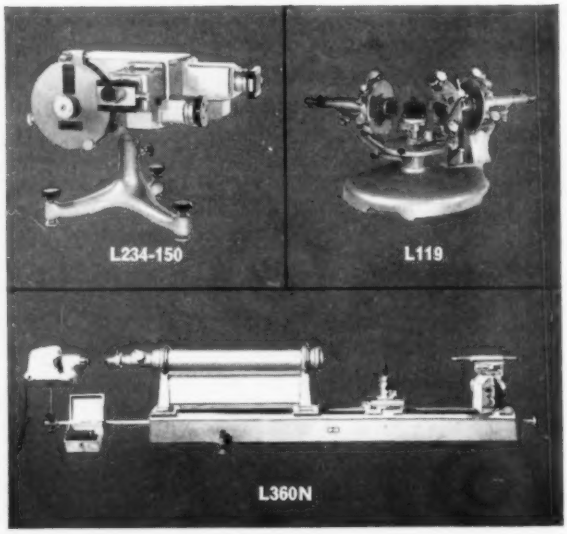

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